

NEW

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# All About Space

## TOUR OF THE

# UNIVERSE

An awe-inspiring journey through space



Explore alien worlds • Discover stunning supernovas • Delve into black holes



# Welcome to the **All About Space** **TOUR OF THE UNIVERSE**

Once upon a time, a man named Neil Armstrong stepped onto the surface of the Moon, declaring it “One small step for man, one giant leap for mankind.” Join us as we step further than you have ever imagined across our Solar System and out into deep space. In this new revised edition, we journey through our home galaxy, explore our neighbour planets and discover the brutal force of our central star. You will find out all about the ongoing search for extra terrestrial life, and delve deep into the effort and research going into the latest discoveries on Pluto. There are so many incredible phenomena to be found in the universe, and you’ll find the greatest and most awe-inspiring here. From colonies on the Moon to galactic ghosts to the wonders of Moondus, prepare to be astonished by the wonder of the universe we live in.







# All About Space TOUR OF THE UNIVERSE

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Discover the wonders of the Universe





Discover the wonders of the Universe

# Discover the Wonders of the Universe

From exploring our Solar System to the mysteries of deep space, find out what makes our universe so amazing

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9



# What is a black hole?

All sorts of weird and wonderful things can happen when a star dies, such as neutron stars and white dwarfs. Undoubtedly the weirdest of them all, however, are the birth of stellar black holes. Like all the best enigmas of the universe, black holes are as misunderstood as they are mysterious and as hard to observe as they are to comprehend.

Stellar black holes are most commonly formed from the remnants of particularly massive stars when they die - their cores collapsing with a staggering force that defies our understanding of the laws of physics. As the star's mass is forced into an ever-smaller space, the gravitational forces involved effectively rips a hole in the fabric of the universe creating a singularity - the point at which all calculations break down, resulting in infinite loop instead of a number. The end result? The total and utter annihilation of matter and an 'ERROR' screen on the physicist's calculator. ■

## Spherical holes

Although it's easier to visualise them as cosmic plugholes, black holes exist in four dimensions (the usual three, plus time), so they'd actually look like a ball, rather than a disc

## Event Horizon

The lip of the black hole separating the chaos below from the relative safety of the rest of the universe is called the Event Horizon. It's the point of no return that even photons can't outrun

## Feeding frenzy

The space approaching the Event Horizon of a black hole isn't as dark as you might think - as particles of matter spiral in, friction heats them to astronomical temperatures

## Size is relative

Black holes come in all sizes: stellar (up to 20 times the mass of the Sun), supermassive (millions of solar masses, found at the heart of galaxies) and microscopic. As small as a single atom, super-tiny black holes with the mass of Mount Everest are thought to have formed at the beginning of the universe

# How the universe will end

Without the theory of the Big Bang we wouldn't have much to go on when it comes to estimating what the fate of the universe may be. Thankfully, we can come up with several theories for how the universe might end based on our observations of the cosmos, namely that it appears to be expanding at an accelerating rate, but some theories suggest this won't be the case forever.

For example, the False Vacuum theory states that a so-called 'metastability event' could cause the vacuum of space to 'ping' into a lower energy state changing the rules of space, time and matter. If this is the case the entire universe could end at any moment.

Other popular views on when and how the universe will end include the Big Crunch, which is the theory that the universe will eventually start shrinking back to a singularity and re-spawn a new universe, possibly signifying the endless cycle of our universe's life and death.

There is also the Big Rip theory, where the expansion of the universe would continue to accelerate at such a rate that all the matter would be forcibly ripped apart at the seams.

However, the most popular of all current theories is the Big Freeze, which simply dictates that the expansion - and cooling - of the universe will continue unabated until everything in it reaches 'absolute

zero'. At this point the universe would cease to move and would become stable, possibly existing forever.

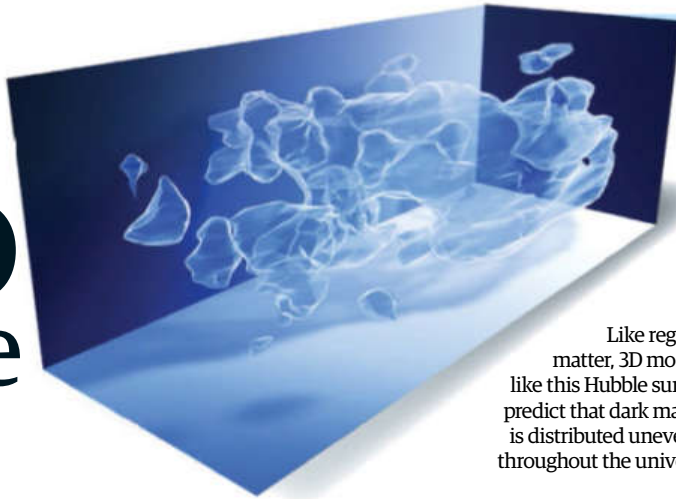
Either that, or our universe could actually be a multiverse and every other possible end to the universe could quite feasibly be happening right now. Since a multiverse of infinite 'verses' would require infinite space and energy, the multiverse would never cease to exist. ■

## Start: The Big Bang

During the first 10-32 seconds following the Big Bang, tiny quantum fluctuations ballooned into a size where they would have been visible to the human eye



# 96% of universe is missing



Like regular matter, 3D models like this Hubble survey predict that dark matter is distributed unevenly throughout the universe

The chilling discovery came to light in the Nineties when astronomers realised the universe's expansion was accelerating instead of slowing, as they'd predicted.

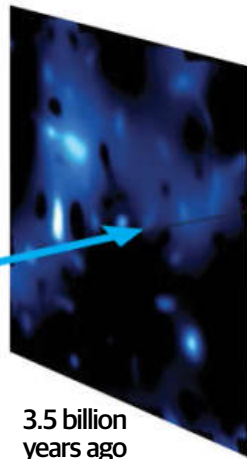
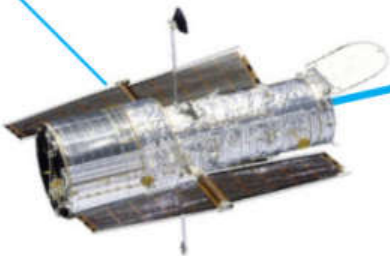
So little is currently known about the mystery, the term 'dark matter' effectively exists as a placeholder - a means to explain an unfathomable problem in a barely more comprehensible way. Thanks to more recent discoveries we do at least have a rough idea of where dark matter resides.

The globular image above depicts the distribution of dark matter across the universe. The COSMOS survey, a Hubble project studying the relationship between large scale structure (LSS) in the universe and dark matter, as well as the formation of galaxies - has offered the most compelling evidence yet that known matter tends to cohabit the same space as the densest concentrations of dark matter. Just don't ask anyone what it is... ■

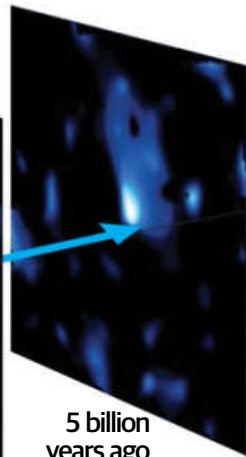
## Finding dark matter

### ■ Dark matter mapping

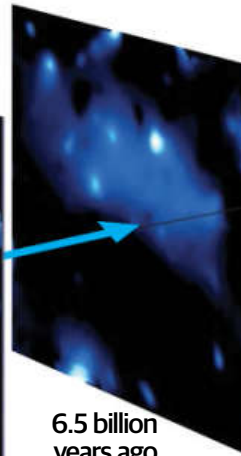
The Hubble Telescope helped create a 3D map that provides the first direct look at the large-scale distribution of dark matter in the universe



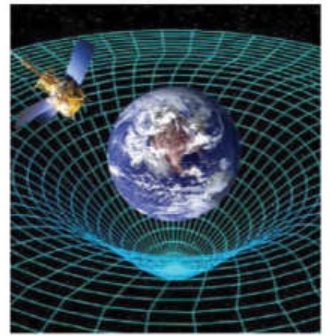
3.5 billion  
years ago



5 billion  
years ago



6.5 billion  
years ago



## Gravity cannot be explained

Gravity is a mind-boggling conundrum. Despite being able to predict its effect with enough scientific accuracy to chart the locations of celestial bodies millions of years into the future, we haven't yet entirely grasped what makes it work.

We know that gravity operates at the speed of light and attracts clumps of matter with a force directly proportional to their mass and is unlike the other three forces of nature, because it has a fundamental relationship with time and space. What we don't know is what particles are actually responsible for creating the force of gravity. Researchers at particle accelerators on Earth like the Large Hadron Collider near Geneva, Switzerland are hoping to find the answer soon.

### ■ First light

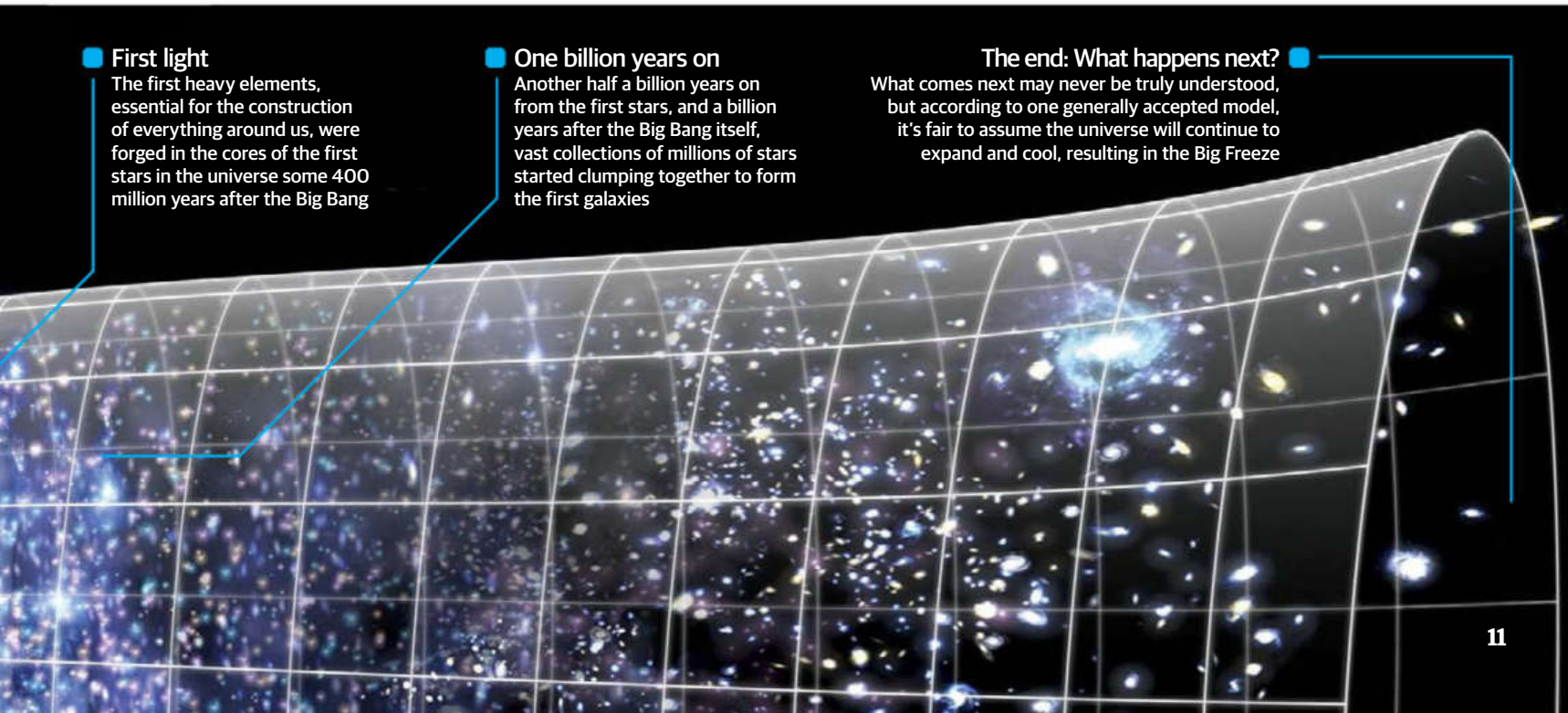
The first heavy elements, essential for the construction of everything around us, were forged in the cores of the first stars in the universe some 400 million years after the Big Bang

### ■ One billion years on

Another half a billion years on from the first stars, and a billion years after the Big Bang itself, vast collections of millions of stars started clumping together to form the first galaxies

### ■ The end: What happens next?

What comes next may never be truly understood, but according to one generally accepted model, it's fair to assume the universe will continue to expand and cool, resulting in the Big Freeze





# Mining asteroids

James Cameron and Google's Eric Schmidt and Larry Page establish the first asteroid-mining company



If successful, Planetary Resources could send robotic mining vehicles to asteroids

It might sound and look like something out of a sci-fi film, but asteroid mining is very much a reality, and one that could greatly benefit humanity. For decades it has been nothing but a pipe dream and, until recently, nobody had been able to devise a clear plan for long-term mining of an asteroid.

That all changed when a new company called Planetary Resources, Inc outlined a clear goal in early 2012 to mine near-Earth asteroids for valuable minerals. Set up by some familiar and rich names, including James Cameron and Google's Eric Schmidt and Larry Page, the company aims to supplement the Earth's natural resources by developing and deploying robotic asteroid-mining vehicles.

Right now, Planetary Resources is still in its very early planning stages, attempting to identify the key technologies that will allow it to produce the necessary machinery to forge these large mining droids. However, the ultimate aim - and one in which its backers readily accept is still a number of decades away - is to survey numerous asteroids for their mineral and water content, before dispatching automated

**"The aim is to survey asteroids for mineral and water content before dispatching automated miners"**

Small, water-rich, near-Earth asteroids could be captured allowing their resources to be extracted



miners to harvest them. Up to five orbital telescopes are expected to be launched by 2014 to begin the survey.

Indeed, the existence of Planetary Resources is fascinating because it is in it for the long haul, creating a completely conceivable roadmap to asset extraction. If successful, the endeavour could prove very profitable for the company, with studies indicating that most asteroids are rich in minerals such as iron, nickel and titanium - which are in restrictive supply on Earth. If these elements could be extracted and processed it would prove invaluable for future industry.

What is most fascinating, though, is that in its mission to mine asteroids, Planetary Resources could actually provide a viable base from which humans could expand into the Solar System. If water, oxygen and construction materials can be acquired from off-planet sources, then the speed and quantity of any planned colonisation project would be dramatically increased. ●

## Who's involved?



**Eric Schmidt**  
Schmidt is the executive chairman of Google. He is also a celebrated software engineer.



**Larry Page**  
Page is the CEO of Google and also its co-founder. He specialises in computer science.

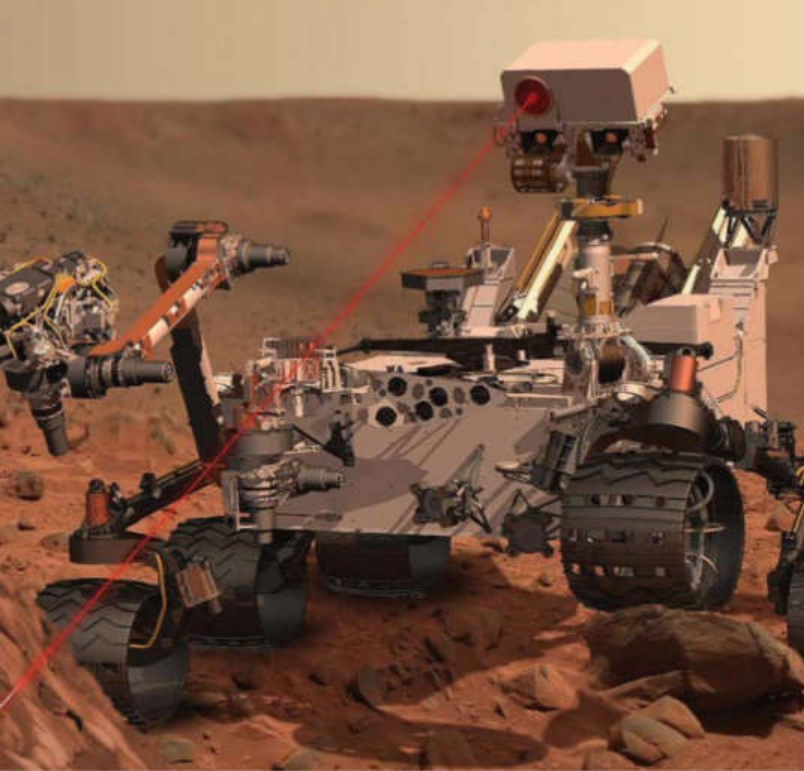


**James Cameron**  
Director of *Aliens* and *Terminator 2*, Cameron also helped build the Deepsea Challenger.



**Peter Diamandis**  
Diamandis is a space-flight entrepreneur and expert in designing space vehicles.





# Firing lasers on Mars

The Science Laboratory mission to land the Curiosity rover on Mars blasted off on 26 November 2011 and is a simply phenomenal project. Once it has parachuted down to Mars, the state-of-the-art vehicle has only one purpose - to help assess the habitability of the Red Planet. It will do this by performing various tests in its onboard laboratory, including large-scale chemical analysis of its rocky surface, using a ChemCam laser to vapourise pieces of the terrain for more effective study. ■



The Universe

## Book a flight to the ISS

SpaceX's Dragon spacecraft is exciting for all the right reasons. As discussed earlier (see page 12) it has already begun cargo missions to the International Space Station, and in the next few years it is set to begin manned expeditions to space, the first private spacecraft ever to do so. It has already received funding from NASA under the Commercial Crew Development programme, and by 2015 at the earliest it is expected to start ferrying up to seven astronauts on each flight to Earth orbit.



## First visit to Pluto

Currently en route to the dwarf planet Pluto, NASA's New Horizons spacecraft holds the record for the highest-velocity ejection speed from Earth's atmosphere of any human-made object. It was fired directly into an Earth-and-solar escape trajectory with the equivalent speed of 58,536 kilometres per hour (36,373 miles per hour)! Upon reaching Pluto in 2015 it will complete the first-ever flybys of the super-cold planet and its moons - Charon, Nix and Hydra - analysing them and their environment with its seven on-board sensors.

# Inflatable space stations

Bigelow Aerospace's inflatable Sundancer space complex is a glimpse into the future of commercial space habitation, laying the groundwork for the BA 330, the first model of its kind to go into production. Launching in a compacted state the Sundancer will expand once it enters orbit. It has been designed with space tourism in mind and, if all goes to plan, could be offering stay-overs within the next decade. ■

### Modules

Just two of these modules would be able to house more people than the entire International Space Station

### Strong material

The expandable body is fabricated from numerous layers of Kevlar-like materials, providing a high resistance threshold and strength to support a large observation window

### Debris shield

The Sundancer has a micrometeoroid and orbital debris shield. This gives it more enhanced protection than currently available on the ISS

### Expandable

Once in orbit tanks release a breathable mixture of oxygen and nitrogen to expand the flexible module to its full size





# Discovering life on Jupiter

The JUICE spacecraft (Jupiter Icy Moon Explorer) - is arguably the most exciting development yet in the search for alien life. The European Space Agency spacecraft, which was selected above a host of rivals for the crucial mission, is due to head to the Jupiter system in 2022 in search of new life forms. Launching on the back of the extremely powerful Ariane 5 rocket, JUICE will engage its solar-powered electric engines and make the long-haul, eight-year flight to Jupiter. Upon arriving, JUICE will analyse the planet, as well as its icy moons Europa, Callisto and - most importantly - Ganymede. Ganymede will be the focus of its 1.4GB daily data downlink as reports indicate that it contains a subsurface ocean. If this is true, then that ocean could be the location of our very first contact with an alien organism. ■

## JUICE

The possibility of finding alien life on Ganymede is the main focus of JUICE's mission to Jupiter

## Life-bearing ocean?

There is a strong chance that Titan has a life-bearing underground ocean of water and liquid ammonia roughly 200km (124 miles) beneath its surface

## Silicate core

Reports indicate that Titan has a silicate core and that its interior may still be hot, with a layer of magma-like material composed of water and ammonia generating heat

## Young crust

Europa's surface is largely crater-free. This leads scientists to believe that it is relatively young and could harbour underground oceans and lakes

## Underground lakes

In addition to a vast underground ocean, studies have shown that huge liquid lakes could also exist, entirely encased within Europa's icy shell

# Underground oceans of Europa

While primarily being sent to search for alien life on Jupiter's moon Ganymede, the JUICE spacecraft will also be deployed to Europa. The reason? Scientists at NASA and the ESA believe it could also harbour life. Indeed every report beamed back to Earth to date has indicated that due to the moon's smooth and youthful surface, there is an excellent possibility that it covers a vast subterranean ocean.

If there is an ocean under Europa, then - as demonstrated in missions down to the bottom of Earth's deepest and coldest oceans, where microbial life is abundant - there is a possibility that some form of life could exist as deep hydrothermal vents emanating up from the moon's core could inject geothermal energy into the waters, providing the catalyst to the creation of life. ■

## Extreme heat

Geothermal heat emanating from the moon's core would penetrate its subterranean ocean and icy shell, generating chemical disequilibria and catalysing the creation of life

## Vast ocean

If Europa had an ocean, it would be vast. Life within it would probably concentrate around hydrothermal vents on the ocean floor, or cling to the lower surface of its icy shell



■ **Earth-like surface**  
Titan's surface is Earth-like, with rivers and lakes of liquid ethane and/or methane potentially providing habitats for non-water-based life forms

■ **Atmosphere**  
Much like its surface, Titan's atmosphere is also very Earth-like. It is dense, chemically active and is privy to weather such as cloud formations and rain

# Titan's Earth-like climate

Saturn's moon Titan is incredibly interesting because it has a dense nitrogen-rich atmosphere and a climate similar to that on Earth, with wind, rain and clouds a frequent occurrence. Indeed, its surface even has similar features, too, such as sand dunes, rivers, lakes and seas - although the latter's 'water' is most likely liquid methane and ethane. As such, it is thought by scientists to potentially be a habitat in which microbial extraterrestrial life could survive, or at the very least, act as a rich prebiotic environment for their future creation. ■

## Oxygen on Ganymede

Reports indicate that oxygen may exist within the atmosphere of Jupiter's Ganymede moon. The oxygen is created when water ice on the moon's surface is split into hydrogen and oxygen by impacting radiation waves, with the hydrogen then proceeding to be lost from the atmosphere quicker than the oxygen due to its low atomic mass. This process leaves a thin layer that includes oxygen, oxygen gas

and ozone. Importantly, however, the presence of oxygen is not direct evidence that there could be life on Ganymede, rather just an extra layer of chemical complexity in which life could, theoretically, be generated. However, the oxygen concentrations on Ganymede are roughly equivalent to those found on Mars, a planet on which scientists believe life could have existed at one time. ■

■ **Going deeper**  
Ganymede has a cold rigid ice crust, an outer warm ice mantle, an inner silicate mantle and a metallic core

## Life in the methane lakes?

One of the best chances of finding life on Titan is within its numerous, large methane lakes. These lakes, which litter the moon's surface, could act as our water-based ones do on Earth.

Critically, however, for this to be possible it would require the alien organism to intake hydrogen rather than oxygen, react it with acetylene instead of glucose and produce methane instead of carbon dioxide.

While sounding far-fetched, it becomes more of a reality when you consider that there are various methanogens (methane-producing microorganisms) on Earth that obtain their energy by reacting hydrogen with carbon dioxide in a very similar way. ■

Bodies of liquid ethane and methane have been detected on Titan by the Cassini-Huygens space probe



# Discovering new Earths

Scientists are busy in their search for new, Earth-like planets outside of our Solar System and new advances in technology may help us find one soon

Planet hunting is a new and exciting area of astronomy barely two decades old that, thanks to missions such as NASA's Kepler telescope, is revealing more and more data about intriguing new worlds outside of our Solar System, known as extrasolar planets or exoplanets. Only in the last 20 years has sufficient technology been available to allow us to categorically prove the existence of these planets. While we're still some way off seeing

detailed imagery of direct exoplanet observations, projects like NASA's James Webb Space Telescope and the European Extremely Large Telescope (E-ELT) will bring Earth-size exoplanets into view and even study the composition of their atmospheres.

The number of bizarre and familiar new worlds just waiting to be discovered is staggering, if estimates prove to be accurate. In our Milky Way alone there could be hundreds

of billions of planets, and so far we've found just a few thousand. The ultimate goal for planet hunting is to find an Earth-analogous planet that could help ascertain whether life could

potentially grab a foothold outside of our Solar System.

The key to discovering an Earth-like planet is to find those that are within the habitable or 'Goldilocks' zone of a star, the area within which the conditions are thought to be 'just right' for water to form. Kepler-22b was the first such planet to be found and, while it is now thought to have a thick atmosphere that may be inhospitable to life, it was very influential in helping to spur the discovery of new Earth-like planets. One example of these was Gliese 581 g, a planet no more than

**"Projects like the James Webb Telescope will bring Earth-sized exoplanets into view"**

## The search for extraterrestrials

Often described as the world's biggest eye on the sky, the European Extremely Large Telescope (E-ELT) is one of a new breed of scopes that will be capable of bringing extrasolar planets, the universe's first objects and black holes into focus.

The E-ELT project, first put into motion in 2005 and due to be operational in 2020, will be based at the world famous Cerro Armazones observatory in Chile.

Its primary light-gathering mirror will measure 39.3 metres (128.9 feet) in diameter and will be constructed from no less than 798 hexagonally shaped mirror segments each measuring 1.4 metres (4.5 feet) across.

### Light bucket

The E-ELT's total light-collecting area will be nearly five times more powerful than anything that exists on Earth today

### 40-metre mirror

Not only will the E-ELT's 40m (131ft) mirror take pictures of larger known extrasolar planets, it's also hoped it will observe Earth-sized exoplanets, too



The E-ELT is huge, as shown by this comparison with London's Big Ben



four times the mass of Earth sitting right in the middle of the habitable zone of its host red dwarf star. While a year on this planet is only 37 days, observations suggest that Gliese 581 g may be a suitable planet on which life could reside.

Another potentially life-harboring planet is HD 85512 b, a so-called 'Super-Earth', like Gliese 581 g, with a mass at least 3.6 times that of our home planet but with a temperature that could potentially allow for the existence of liquid water, which is thought to be one of the key components for life to form or survive. Over the next few years, as our methods of finding and characterising exoplanets become more and more sophisticated, it's likely that more Earth-like planets like these will be discovered all over the Milky Way. ■

## 3 amazing Earth-like planets

m = mass of the Earth  
r = radius of the Earth



### Gliese 581 g

**Distance from Earth:** 20 light years  
**Star:** Gliese 581 **Constellation:** Libra  
**Discovered:** 2010  
**Mass:** 3.7m **Radius:** 1.3r  
**Temperature:** -20°C



### HD 85512 b

**Distance from Earth:** 36 light years  
**Star:** HD 85512 **Constellation:** Vela  
**Discovered:** 2011  
**Mass:** 3.6m **Radius:** Unknown  
**Temperature:** 25°C



### Kepler-22b

**Distance from Earth:** 620 light years  
**Star:** Kepler-22 **Constellation:** Cygnus  
**Discovered:** 2009  
**Mass:** Unknown **Radius:** 2.4r  
**Temperature:** -11.15°C

## Most spectacular telescope ever

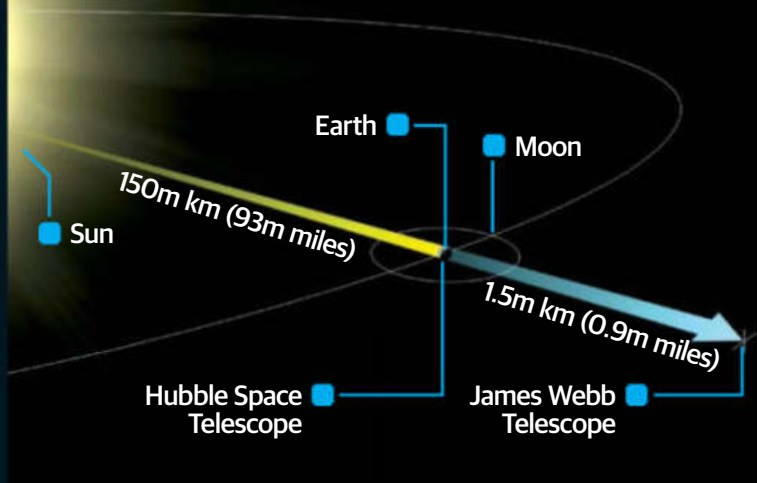
Named after the NASA administrator who created the Apollo space programme, the James Webb Space Telescope (JWST) is set to blast off to Earth orbit in 2018. Although often described as the successor to Hubble, the JWST will be a very different beast. First, it's much bigger. While Hubble was 13 metres (42 feet), JWST's sun shield alone is nearly twice the length at 22 metres (72 feet). The diameter of the primary mirror puts Hubble's 2.5-metre (8.2-foot) offering in the shade, too - at 6.5

metres (21.3 feet) it has a total light-collecting area of nearly 15 square metres (161.4 square feet).

JWST is also designed to do its work in the infrared end of the spectrum, as opposed to Hubble's optical (and ultraviolet) wavelengths. This will let us see through the dust that clogs our view to the centre of our galaxy to offer us a glimpse of the supermassive black hole that resides there and investigate accretion discs of young stars so we can see how solar systems - and planets - form. ■

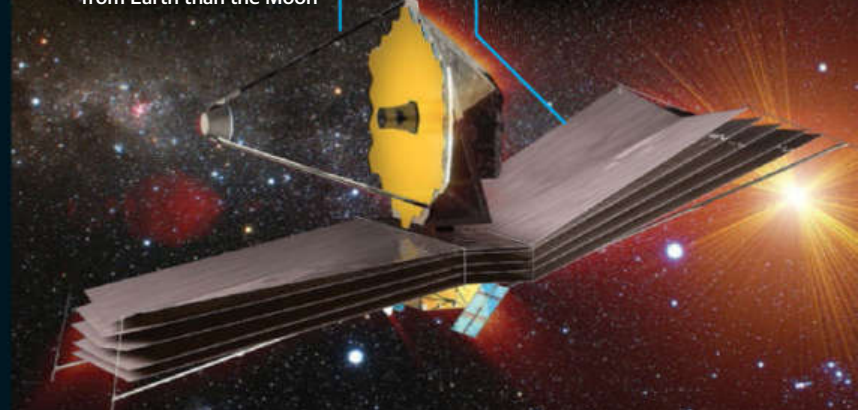


### Where will the JWST be?



**Lost in space**  
The JWST won't orbit the Earth. Sitting at the Earth-Sun L2 Lagrange (L2) point it will be nearly four times further away from Earth than the Moon

**Sun shield**  
Five layers of sun-shielding will simultaneously protect the mirrors and sensitive instruments from the light of the Sun, Earth and Moon





Discover the wonders of the Universe

Betelgeuse to  
go supernova



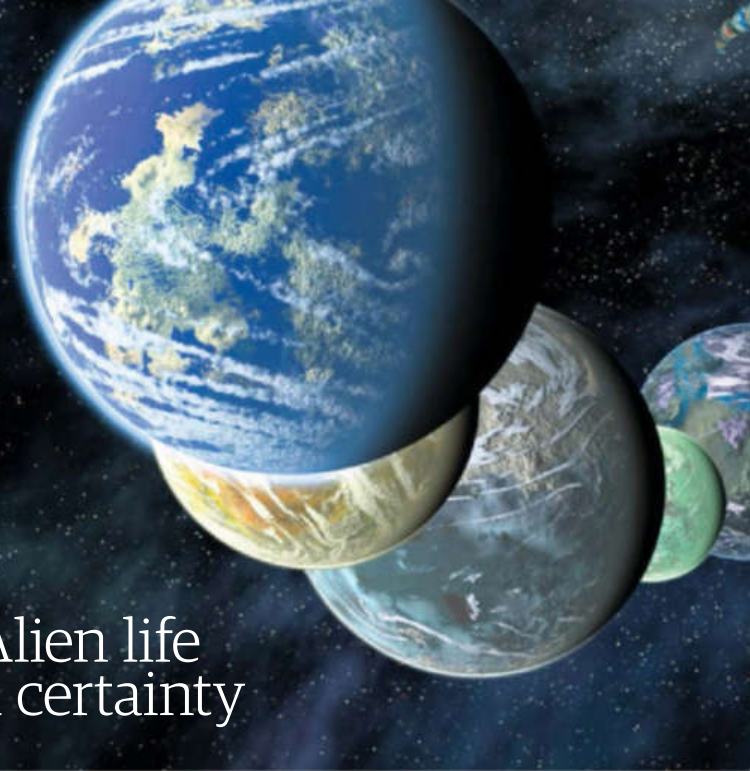
Space Shuttle  
is no more



More water  
on Europa  
than Earth



Alien life  
a certainty



# 10 fascinating space facts you need to know

Meteorite-sized nuggets of fantastic  
space info that will blow your mind

## **Betelgeuse could go supernova**

The red super giant star Betelgeuse is due to die at any moment. The event could see the star reach a comparable brightness to that of a full moon.

## **The Space Shuttle is no more**

NASA's youngest Space Shuttle, Endeavour, having flown its last mission in May 2011 is now on display at the California Science Center in LA.

## **There's more water on Europa than Earth**

Data acquired by NASA's Galileo spacecraft suggests there is up to three times more water under the surface of Saturn's moon Europa than on Earth.

## **The chance of extraterrestrial life is 100 per cent**

That's according to the Drake equation, a mathematical equation used to estimate the number of extraterrestrial civilisations in our Milky Way galaxy. Mr Drake's own estimate came to over 10,000 alien civilisations.

## **Virgin Galactic set to take tourists into space**

From late 2012 Spaceport America began hosting the first-ever space tourism flights courtesy of Virgin Galactic. It has 400 accepted reservations already on the books.

## **A soup can's worth of a neutron star would weigh more than the Moon itself**

A neutron star is formed when a star of between eight and ten solar masses dies. A teaspoon of it would weigh more than everyone on Earth, while a soup can would weigh more than the Moon.

## **World's biggest telescope array set for completion**

In 2012 the Atacama Large Millimeter/sub-millimeter Array (ALMA) in Chile was completed and consist of 66 twelve-metre and seven-metre diameter radio telescopes. It will be the biggest until the completion of the Square Kilometre Array in 2019.

## **The Moon is moving away**

The Moon has been moving 38 millimetres away from the Earth every year since its formation.

## **Humans are going to Mars**

NASA and Lockheed Martin hope to send humans to Mars by 2035 with the jointly created Orion spacecraft.

## **The Sun loses a billion kilograms every second**

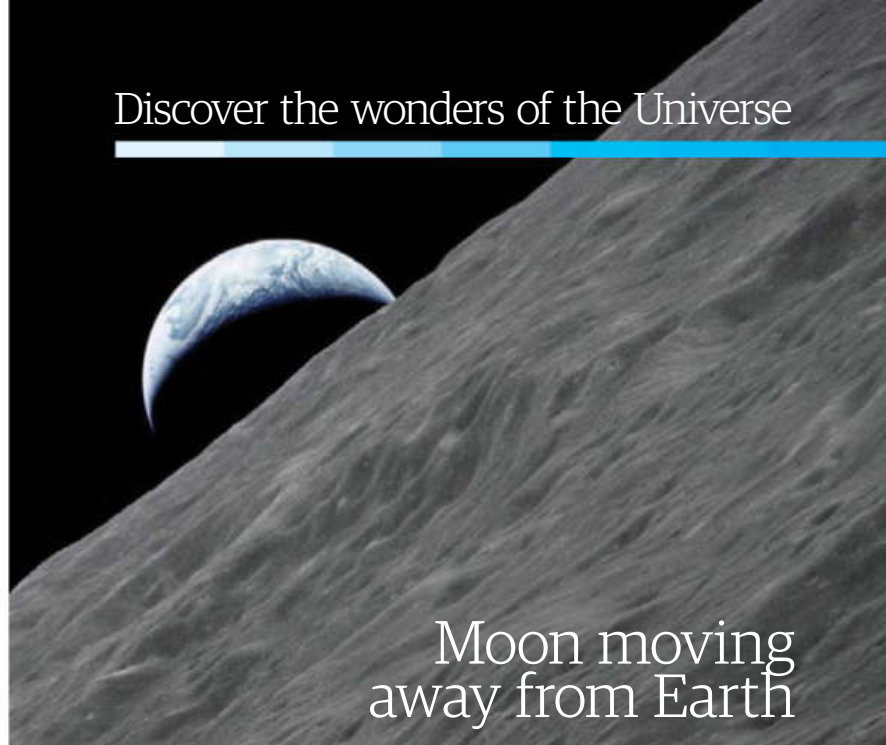
The sun burns through a billion kilograms of its own mass each second. That works out at about three Empire State Buildings every second! ●





Space tourism is go

Discover the wonders of the Universe



Moon moving away from Earth

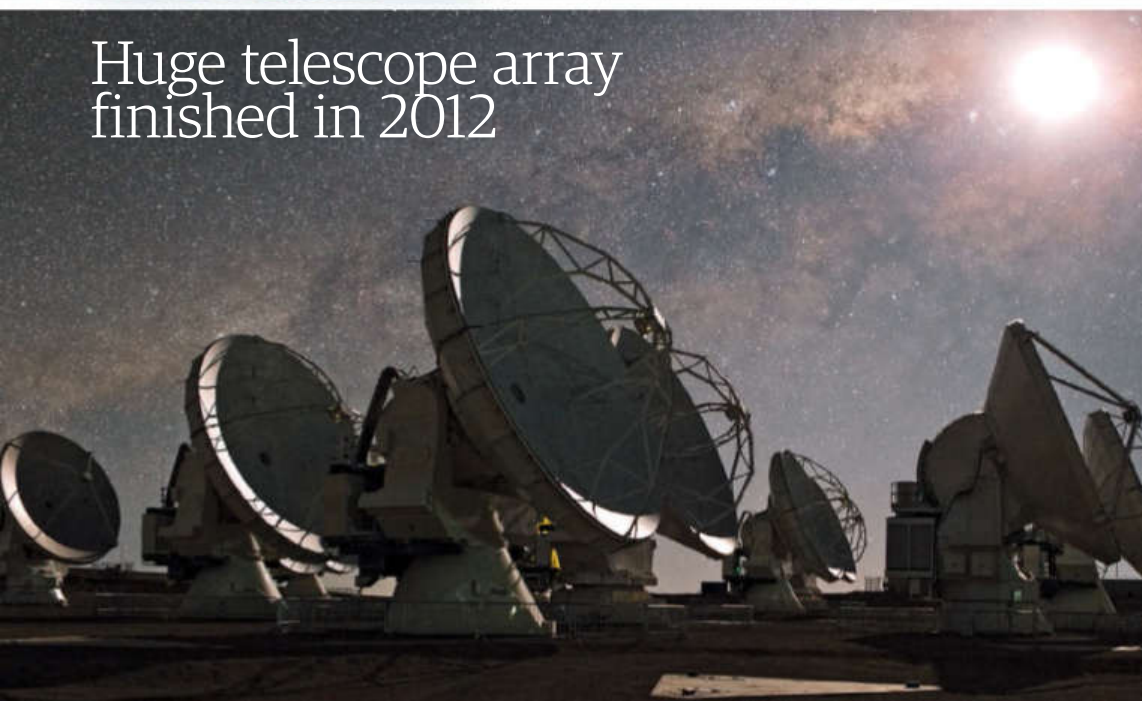


A tin heavier than the Moon



Mankind heading to Mars

Huge telescope array finished in 2012



The Sun is losing weight



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# JOURNEY THROUGH THE MILKY WAY

Our home in the universe is a giant spiral system containing many billions of stars - but how much do we really know about it, and what do we still have to learn?





Look up at the sky on a dark, clear night and you can't miss the Milky Way - a broad swathe of pale light winding its way around the sky among many of the brightest individual stars. Ancient astronomers saw it as a stream of milk spilt across the sky by the goddess Hera when she suckled the hero Hercules, but today we know the Milky Way is something very different - an enormous disc of stars some 100,000 light years across, containing (at the latest estimate) around 200 billion individual stars.

Unsurprisingly, then, our Solar System is an insignificant speck within the overall scale of the Milky Way - all the planets and other large bodies orbiting the Sun are confined to a region just a few light *hours* across. In our part of the galaxy, stars are spaced far enough apart that even our nearest stellar neighbours appear as mere specks of light. The closest of all, the triple star Alpha Centauri, is still around 4.3 light years away.

The overall shape of our galaxy has been likened to two fried eggs placed back to back, with a broad, flat disc of scattered stars, gas and dust surrounding a bulging central hub where stars are more densely packed together. Our Solar System and its neighbours lie in a relatively sedate, outlying region of the Milky Way, about halfway between the centre and the edge. With a little understanding of the Milky Way's structure, the band of light across the night sky is easy to understand: when we look across the plane of the Milky Way's disc, we see far more stars lying in any given direction and these effectively merge together into a generalised glow. On the other hand, when we look 'up' or 'down', out of the galactic plane, we are staring into largely empty intergalactic space, with only relatively nearby stars in our part of the disc to get in the way.

In 1785, astronomer William Herschel made the first attempt to map the Milky Way in detail, by

exhaustively counting the number of stars he could see in different directions across the sky. He proved beyond doubt that the Milky Way was a flattened plane, but unfortunately misunderstood its shape because he believed that our own Solar System was near the centre of the galaxy.

In the late-Twenties, Jan Oort set out to study the movement of individual stars in different parts of the sky. He soon confirmed that the Milky Way is rotating, showed that its centre lies in the direction of the constellation Sagittarius, and also proved that galaxies do not rotate like solid bodies - instead the stars closer to the galactic hub move more quickly along their orbits, while stars further out circle more slowly - a phenomenon known as 'differential rotation'. The Sun, for instance, takes around 200 million years to complete a single orbit. Later measurements in different parts of the disc showed that orbital speeds do not change as dramatically as



they should do if they are governed by the mass of the Milky Way's visible matter alone - evidence that our galaxy contains large amounts of transparent but weighty 'dark matter'.

Even today, our understanding of our galaxy is constantly evolving thanks to new theories and new observing technologies. Radio, infrared, ultraviolet and X-ray observations can pierce the dense clouds of stars and dust that obscure large parts of the Milky Way in visible light, while new analytical techniques allow astronomers to learn far more from the stars we can observe. So what is our current understanding of this enormous stellar system?

The Milky Way is a barred spiral galaxy, around 100,000 light years across and with a disc roughly 1,000 light years thick in most places. Its central hub

# "The most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms"

is formed by a densely packed ball of stars roughly 8,000 light years in diameter, out of which a bar of stars some 27,000 light years long emerges. The bar points more or less directly towards our Solar System, and as a result its existence was uncertain until it was finally confirmed by NASA's infrared Spitzer Space Telescope in 2005.

Two major spiral arms emerge from the ends of this bar. Until recently, our galaxy was thought to

have four major arms, but further observations have led to two of them being 'downgraded'. The two survivors are known as the Scutum-Centaurus Arm and the Perseus Arm. They alternate with the two recently demoted arms - the Sagittarius and Norma arms. The picture is complicated by numerous other disconnected regions that follow the general sweep of the spiral arms. For instance, our own Solar System lies on the inside edge of a 10,000 light year fork in the Sagittarius Arm, known as 'Orion Spur', while both the Sagittarius and Norma arms are thought to trail off into disconnected clumps that wrap their way around the galaxy's outer perimeter. The outer extension of the Norma Arm, which lies on our side of the galactic centre and is therefore more easily seen, is known as the Outer Arm.

The Milky Way's spiral arms are not permanent, linked structures - otherwise the differential rotation discovered by Jan Oort would cause them to 'wind up' after just a few rotations. Instead, they perpetually renew themselves. In fact, the arms seem to be celestial traffic jams, created where stars and gas in circular orbits around the galactic hub enter a spiral 'density wave' region where they are slowed down and jammed together. This triggers the creation of new star-forming nebulae that light up the spiral arms with the pinkish glow of hydrogen emission, and ultimately give birth to 'open clusters' of stars.

However, these stellar foundries are short-lived on a galactic timescale - they exhaust their supplies of star-forming gas within a few million years, and the heaviest stars squander their fuel in a few million more. As a result, the most brilliant stars don't survive long enough for their orbits to carry them out of the spiral arms - instead it's the more sedate, longer-lived stars like our own Sun that make it out of the traffic jam to continue their orbits around the galactic disc over billions of years.

### Background glow

While the major star clouds of this region are all in the intervening spiral arm, the diffuse glow of stars in the galactic hub, more than 20,000 light years away, shines out from beyond

### Small Sagittarius Star Cloud

This dense cluster of stars lies in the Carina-Sagittarius spiral arm. It is 6,000 light years deep and centred roughly 13,000 light years from Earth

### Great Rift

A dark lane of dust just 300 light years from Earth appears to split the Milky Way in half where it is silhouetted against the more distant spiral arm

## Viewing our galaxy from Earth

As early as the 18th Century, astronomers realised that the winding path of the Milky Way across the sky is a result of our location in a broad, relatively flat plane of stars. But our Solar System's location sandwiched between the major spiral arms complicates the picture considerably, so that different arms in different parts of the sky run together and overlap in places to form a seamless river of light. The picture is further complicated by the presence of dark dust lanes that obscure

the light of more distant star clouds: perhaps the most famous of these is the Great Rift, which runs through the constellations of Cygnus and Aquila. The brightest and broadest part of the Milky Way, meanwhile, lies in the direction of Sagittarius and Scorpius. It consists largely of the Carina-Sagittarius Arm and marks the direction of the hub and galactic centre. On the opposite side of the sky, meanwhile, the Perseus Arm runs around the outer edge of the galaxy as seen from our point of view.

## Birth of the Milky Way

### 1. Raw ingredients

The Milky Way is thought to have originated from the coming together of a number of smaller irregular clouds of stars as well as gas and dust within a couple of billion years of the Big Bang in which the universe itself was born

### 2. Giant star cloud

Initially, the combined cloud would have had a slow rotation in a more or less random direction. As it collapsed inwards under its own gravity, it gradually began to spin more rapidly

### 3. Flattening out

Clouds of gas and dust in random orbits would have tended to collide and merge, cancelling out their random motions until they were concentrated in a single plane. Collisions between more widely spaced stars were rarer, so the old stars remained in the halo

### 4. Dominant disc

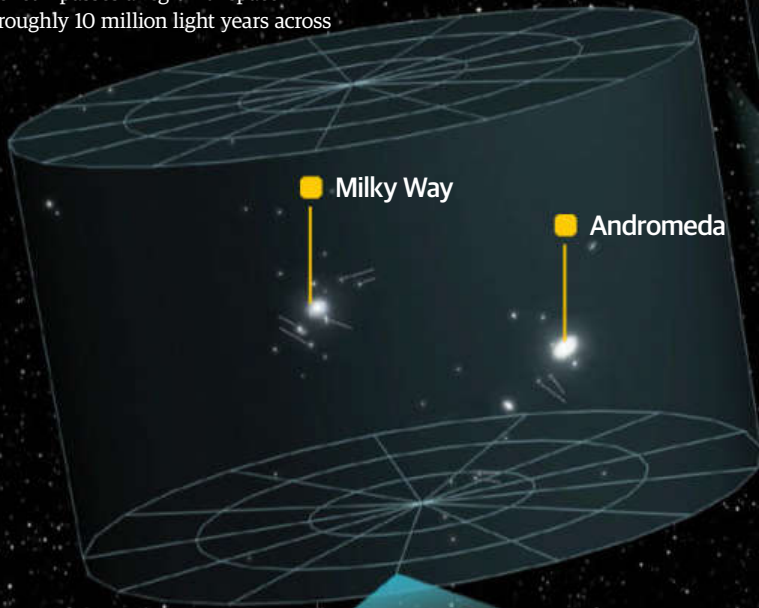
As the galaxy evolved, new stars formed only in the disc and hub regions, leaving the halo as an ancient remnant of the galaxy's earliest star



# Where is our galaxy?

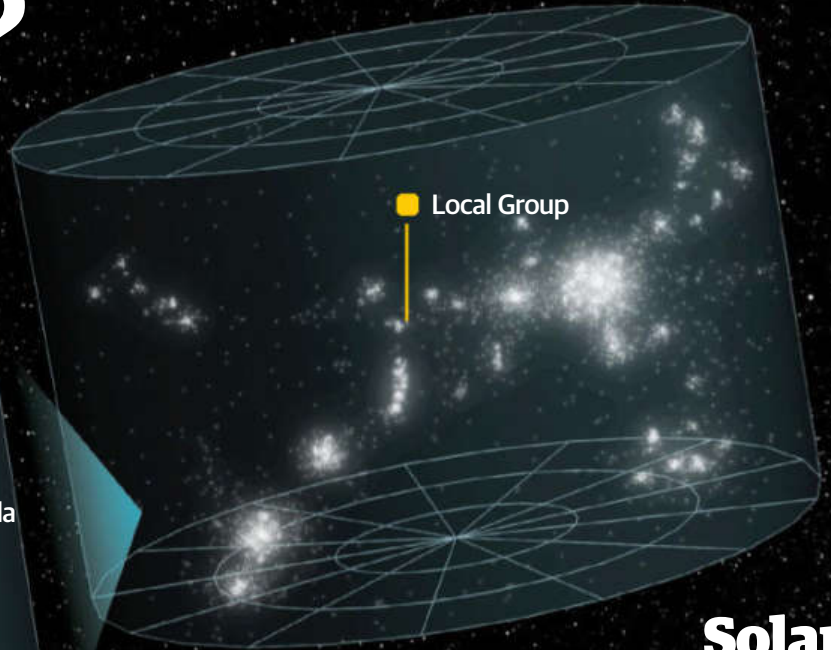
## Local Group

This cluster of galaxies, dominated by the Milky Way and Andromeda, encompasses a region of space roughly 10 million light years across



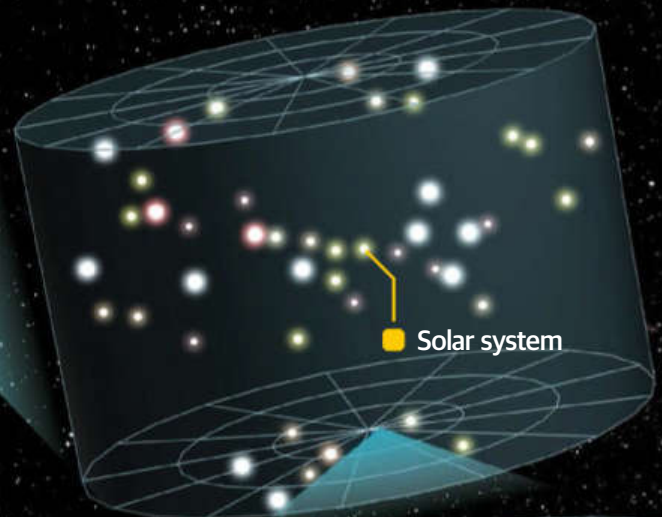
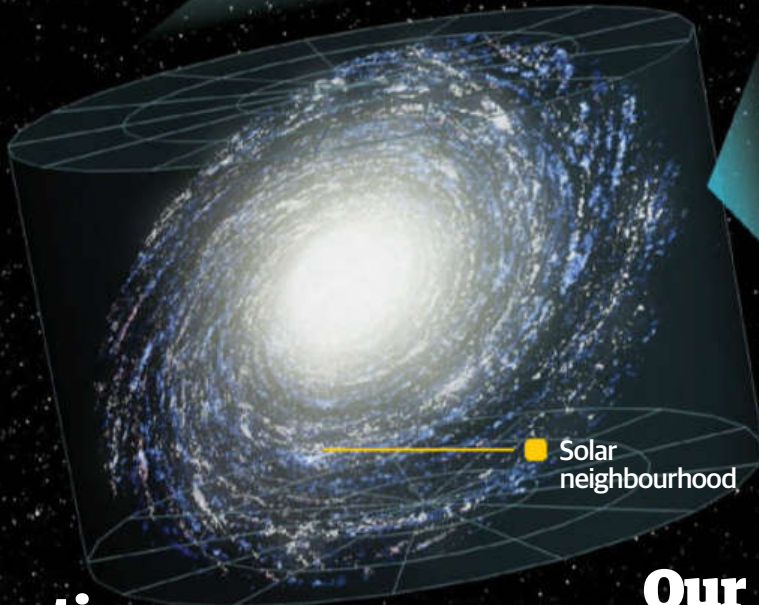
## Virgo Supercluster

The Local Group lies on the outskirts of a galaxy supercluster centred around the Virgo Cluster, some 60 million light years away



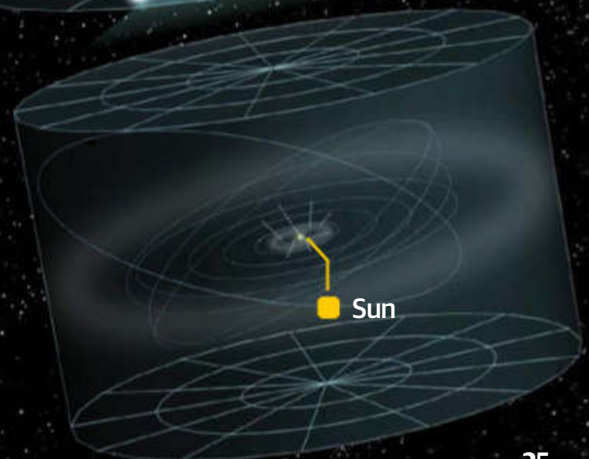
## Solar neighbourhood

Our region of the Milky Way contains a mixture of single and multiple stars of many different types, separated by a few light years on average



## Our Solar System

Out to the edge of the Kuiper belt (the zone of small, distant icy dwarf worlds) our Solar System is roughly a light day across



## Galactic influence

The Milky Way is roughly 100,000 light years across, but its gravitational influence covers a region several hundred thousand light years wide



## Explore the Galaxies

At the inner limit of the spiral arms, the bar and hub are surrounded by a structure known as the 5-kiloparsec Ring (one kiloparsec is around 3,260 light years). Although we cannot see it in visible light, the ring seems to contain huge concentrations of star-forming nebulae and young stars: it's probably the main generator of new stars in the Milky Way.

Above and below the main disc lies a relatively empty region known as the halo. Many faint, long-lived stars pass through this region on tilted orbits, but the halo's most obvious occupants are globular clusters - dense balls containing many tens of thousands of old, red and yellow stars that are generally found above and below the galactic hub. Similar red and yellow stars dominate the hub and bar - they are relatively poor in heavy elements, which allows them to shine for billions of years

without evolving significantly. As a result, they are known as 'Population II' stars, in contrast to the younger, faster-evolving and heavy-element-enriched 'Population I' stars in the galactic disc.

Among all these stars, the huge majority are low-mass red and orange dwarfs - stars with a fraction of the mass of the Sun, which shine so faintly that they can only be seen when they are relatively nearby. Brighter and more massive stars are much rarer, but tend to shine out over huge distances and so appear more prominently in our skies. Similarly, ageing but brilliant red and orange giants are common among the naked-eye stars seen from Earth, but in fact far rarer than they might appear at first glance.

What's more, stars in our galaxy seem to be gregarious - although they gradually drift apart from the open clusters in which they form, many stars

remain together in binary or multiple star systems. Recent research also suggests that planetary systems are also common - there may be at least as many planets as there are stars in the sky.

Within the hub, stars become more densely packed towards the centre of the Milky Way - the galactic core. Only X-rays, radio waves and some infrared waves can pass through these dense star clouds unaffected, but they reveal an intriguing picture of the strange and violent conditions in the core itself.

At radio wavelengths, the core is marked by a complex radio source known as Sagittarius A - it consists of a bubble-like structure (Sagittarius A West) a few tens of light years across - probably the remnant of an enormous supernova explosion. Embedded within this is a three-armed spiral called Sagittarius A East, roughly ten light years across. The middle of the spiral coincides with the densest concentration of stars in the Milky Way, and a third, point-like source of radio waves known as Sagittarius A\* that is believed to mark the Milky Way's centre.

X-ray emissions reveal huge bubbles and twisted lobes of superhot gas across the region - a mix of supernova remnants and the effects of hot stellar

"The Milky Way is a major component of the Local Group - a small galaxy cluster some 10 million light years across"

### Gaze into the galactic centre

This huge mosaic image offers the most detailed view yet of stars around the galactic centre. Covering some 315 square degrees (a little less than one per cent of the entire sky) it contains at least 84 million individual stars, and an incredible nine gigapixels of data at full resolution. The image was created using the 4.1-metre VISTA telescope operated by the European Southern Observatory in Chile. It combines views taken at different wavelengths through five separate near-infrared filters over nearly 2,000 hours of observing time. The infrared detectors on VISTA (the Visible and Infrared Survey Telescope for Astronomy) allowed it to peer through the cool clouds of intervening dust to reveal the hub of the Milky Way in unprecedented detail - the resulting image captures ten times as many stars as any previous survey of the region.

#### Lagoon Nebula

This large and famous star-forming nebula, also known as Messier 8, lies on the nearside of the Carina-Sagittarius spiral arm, just 5,000 light-years from Earth

#### Galactic centre

Even at the enormous resolution achieved by the VISTA image, the supermassive black hole and its surrounding star cluster are lost in an intense blaze of starlight

#### Dark tendrils

In places even the multiple infrared views captured by the VISTA project cannot penetrate the dense intergalactic dust

#### Cat's Paw Nebula

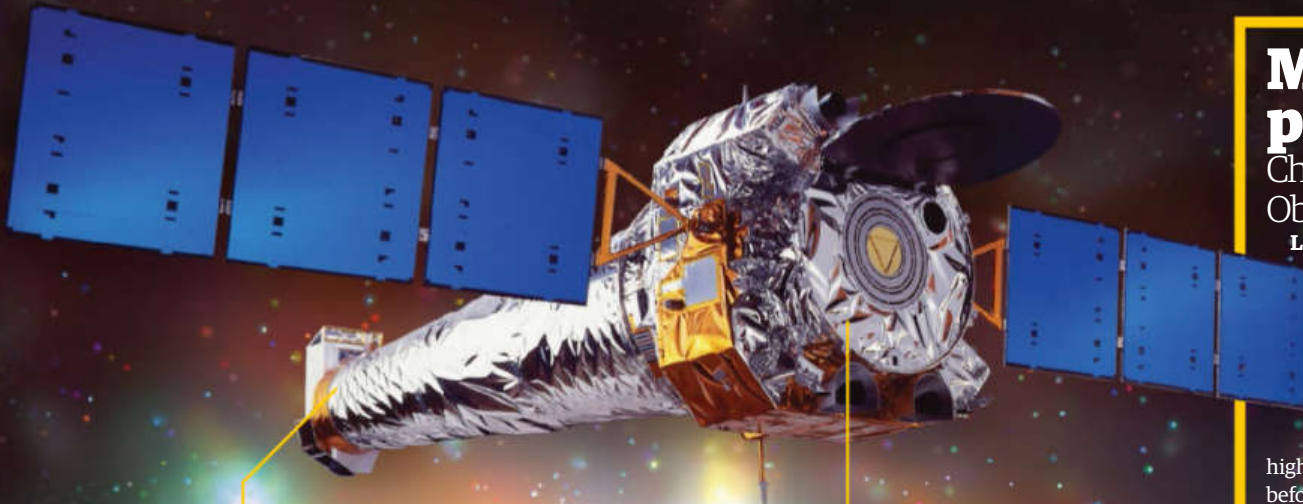
This famous star-forming nebula in Scorpius lies around 5,500 light years from Earth, and is also located on the nearside of the Carina-Sagittarius spiral arm

#### NGC 6441

At a distance of roughly 38,000 light years from Earth, this dense globular star cluster, lies below the plane of the Milky Way in Scorpius, on the opposite side of the galactic centre. It is just one of many such clusters captured in the VISTA mosaic



# Studying the Milky Way



**Detector instruments**  
Two different instruments - the High-Resolution Camera and the Advanced CCD Imaging Spectrometer - can record images from the X-rays or detect their different energy levels

**Mirror assembly**  
Powerful X-rays pass straight through normal mirrors, so Chandra uses a series of nested metal cones at shallow angles, which ensure the X-rays ricochet to a focus

## Mission profile

### Chandra X-ray Observatory

**Launch date:** 23 July 1999

**Launch vehicle:** Space Shuttle Columbia

**Mass:** 4,790kg

**Telescope diameter:** 1.2m

**Mission:** Chandra was designed to image the high-energy X-ray sky at higher resolutions than ever before, detecting phenomena such as hot interstellar and intergalactic gas clouds, black holes and other stellar remnants.

**Key discoveries:** Chandra has allowed the region around Sagittarius A\* to be imaged in detail, while the X-ray echoes it has detected have shown that the supermassive black hole has been active in the recent past.



**Sun shield**  
Spitzer's ingenious solar shield allows it to continue operating at low temperatures even after its liquid helium coolant has been exhausted

**Cool telescope**  
Spitzer collects infrared with a beryllium-mirrored telescope that was cooled to  $-268^{\circ}\text{C}$  ( $-450^{\circ}\text{F}$ ) using liquid helium so as not to swamp the weak heat radiation

## Mission profile

### Spitzer Infrared Space Observatory

**Launch date:** 25 August 2003

**Launch vehicle:** Delta II

**Mass:** 950kg

**Telescope diameter:** 0.85m

**Mission:** Spitzer was designed to study a wide range of objects, from star-forming nebulae and newborn solar systems to distant galaxies. Although the coolant required for its primary mission was exhausted in May 2009, it is still operational in its 'Warm Mission' phase.

**Key discoveries:** Spitzer's infrared vision allowed it to pierce the dust that blocks our view of the galactic centre, providing the first detailed images of the giant star clusters and tortured gas clouds found in the region.



# Map of the Milky Way

## Zone of Avoidance

This mysterious region lies on the opposite side of the hub from our Solar System, and is largely unknown. As well as features of the Milky Way, it also conceals galaxies in the space beyond

## Carina-Sagittarius Arm

This minor arm runs in front of both the Scutum-Centaurus arm and the galactic hub as seen from Earth. It contains some of the richest starfields and most impressive nebulas in the sky

## 5kpc ring

This ring of stars, gas and dust is thought to be the biggest and brightest centre of star formation within our galaxy

## Perseus Arm

This major arm emerges on the far side of the central bar, and wraps its way around the opposite side of the sky from the hub, as seen from Earth. It contains many of the rich starfields and nebulas seen in the northern Milky Way

## You are here

Our Solar System lies roughly 26,000 light years from the galactic centre, about half way between the hub and the galaxy's visible edge. Here, the Sun orbits the centre every 200 million years



## Galactic halo

The halo region above and below the galaxy's flattened disc is home to stray ancient stars and globular clusters - huge balls of long-lived red and yellow stars



## Scutum-Centaurus Arm

This major spiral arm emerges from the near end of the galaxy's central bar, but lies largely on the opposite side of the hub from Earth

## SagDEG

Discovered in 1994 as an unusual concentration of stars on the far side of the galactic hub, the Sagittarius Dwarf Elliptical is a small galaxy in the process of being torn to shreds by the Milky Way's gravity

## Sagittarius A\*

The supermassive black hole at the centre of our galaxy weighs more than 4 million Suns, but only gives its presence away through X-ray and radio emission

## Galactic hub

The central bulge of the Milky Way is roughly 8,000 light years in diameter and dominated by tightly packed, long-lived red and yellow stars

winds blowing out from massive stars. Infrared telescopes, meanwhile, show the distribution of stars themselves - the region is home to two of the largest open clusters in the galaxy, the Quintuplet Cluster and the Arches Cluster. A third cluster surrounds the Sagittarius A\* region itself, but while its individual stars have been mapped, none coincides exactly with the mysterious radio source.

Since the Seventies, astronomers have suspected that Sagittarius A\* might mark the location of an invisible black hole with the mass of millions of Suns, but the evidence to back this up has only recently been found. By mapping the central star cluster over several years, astronomers have plotted the orbits of two stars that orbit the object every few years. Based on the speed of these stars, Sagittarius A\* must contain the mass of at least 4 million Suns concentrated in a region roughly the size of Uranus's orbit around the Sun. With such enormous density, it can only be a supermassive black hole.

However, Sagittarius A\* seems surprisingly quiet compared to similar objects elsewhere in the universe - other supermassive black holes in distant galaxies wreak havoc with their surroundings. Astronomers think the big difference is that these black holes are feeding on material that strays too close. Sagittarius A\*, on the other hand, seems to have long ago cleared out its immediate surroundings, and anything that still orbits in the central region stays safely out of reach.

Recent discoveries, however, suggest that Sagittarius A\* may have been active surprisingly recently. In 2007, NASA's Chandra satellite discovered X-ray 'echoes', created as radiation when an event roughly 50 years previously affected gas clouds near the central black hole. It seems likely that Sagittarius A\* took a substantial snack at this time, when a large gas cloud strayed too close. And in 2010, the Fermi Gamma-ray Space Telescope found evidence for an even larger outburst thousands of years ago.

There's one final question that's worth asking about our galaxy - where does it end? Although the spiral arms seem to lose their intensity and the number of disc stars falls off dramatically over 50,000 light years from the hub, a disc of neutral hydrogen gas extends out to almost 100,000 light years and seems to retain the overall spiral structure. The Milky Way's gravitational influence extends even further - the halo of stars and globular clusters reaches out to around 150,000 light years or more. However, beyond this distance the orbits of halo objects are disrupted by two interlopers - the Magellanic Clouds. Until recently, these two irregular clouds of gas were believed to be in orbit around our galaxy, but it now seems that they are merely passing by on their own paths through space.

On a larger scale, the Milky Way is one of the major components of the Local Group - a galaxy cluster 10 million light years across. The other is the Andromeda Galaxy, some 2.5 million light years away. These two galaxies exert a strong influence on everything in their vicinity, and are approaching each other at 110 kilometres per second. They will eventually collide and merge together about 4 billion years from now in a process that will signal the end of the Milky Way as an independent galaxy.





# The 1969 Lunar lander

The Lunar Module was the first manned spacecraft specifically built to deliver men to the Moon

This two-stage spacecraft was built by the Grumman Aircraft Engineering Corporation to ferry two astronauts and scientific equipment to the surface of the Moon. The 6.7-metre (22-foot) tall craft had an aluminium frame with titanium fittings and was covered with layers of aluminised Kapton and aluminised Mylar to provide thermal protection against micrometeoroids.

The Apollo Command Module carried it into lunar orbit, and two of the three crew transferred to it and used the descent engine to land on the Moon. After deploying scientific experiments and collecting samples, the ascent stage blasted off using the descent stage as a launching pad. Back in lunar orbit, it docked with the Command Module, and once the astronauts were back on board the

ascent stage was jettisoned. Before the Lunar Module (LM) could be used for the Moon landing mission it went through a rigorous programme of development and testing.

In 1962, the first designs envisaged a squat vehicle with large windows but by 1965 it evolved into a lighter and taller, triangular-windowed craft.

The Apollo 5 mission was the first test flight of the LM-1 on 22 January 1968. A Saturn 1B rocket put the unmanned craft into Earth orbit where the descent and ascent rocket engines were tested to simulate a mission abort and a deceleration burn required for a lunar landing.

The mission was deemed so successful that a further test mission with LM-2 was abandoned. Apollo 9 became the first manned mission for LM-3 ('Spider'), which was launched

into Earth orbit on 3 March 1969. Commanded by James McDivitt, the systems of the LM were tested and it performed docking manoeuvres with the Command Module.

LM-4 'Snoopy' was the first LM to be tested in lunar orbit, and its closest approach took it within 15.6 kilometres (9.7 miles) of the Moon before it returned to the Command Module. This dress rehearsal in May 1969 went perfectly but the LM was a test version that was too heavy to launch itself off the lunar surface.

Finally, Apollo 11's LM-5 'Eagle' took Neil Armstrong and Buzz Aldrin to the Moon on 20 July 1969. However, it was not a straightforward landing as the astronauts had to override their craft's computer otherwise they would have landed in an unplanned rocky area. Apollo 12's LM-6 'Intrepid'

in November 1969 also made a successful landing on the Moon. Despite the odd glitch, the Moon missions ran successfully until the Apollo 13 mission.

At a distance of around 320,000 kilometres (200,000 nautical miles) from Earth an oxygen tank in the Command Service Module exploded, and it immediately became a mission to safely return to Earth rather than a trip to the Moon. For four days the crew took refuge in the LM-7 'Aquarius' until they could use the Command Module to re-enter the Earth's atmosphere.

From Apollo 12 to Apollo 14, which used LM-8 'Antares' to land on the Moon in February 1971, H-series precision Landing Modules were used that could sustain two-day long stays on the Moon. LM-9 a H-series module was scheduled for the Apollo 15, but it was replaced with the improved J module series that carried the Lunar Roving Vehicle. J-series modules continued to be used up to the last Apollo 17 mission in December 1972.

In the late-Sixties, there were plans for an LM Truck that would replace the manned ascent stage of the LM with a cargo-carrying stage. This would be capable of delivering 5,000 kilograms (11,000 pounds) of equipment and supplies to support manned Lunar activities.

It is remarkable that after more than 40 years this is the only manned vehicle to land on the Moon. ●



## Inside the Apollo lander

### Ascent stage

This 2.8m (9.2ft) high and 4.0m x 4.3m (13.2ft x 14.1ft) wide, irregular-shaped stage is mounted on top of the descent stage. It carries the astronauts to and from the surface of the Moon

### Antenna

The parabolic S-band steerable antenna provides a voice and data communications link with the Manned Space Flight Network. The parabolic rendezvous radar antenna is used when docking with the Apollo Command Module

### Crew compartment

The pressurised compartment has a volume of 6.7m<sup>3</sup> (235ft<sup>3</sup>); just big enough to house two astronauts

### Fuel tanks

An oxidiser (nitrogen tetroxide) tank and fuel (aerozine 50) tank power the ascent engine

### Reaction control thruster assembly

Four clusters of thrusters can be individually fired for a few milliseconds to make fine attitude corrections, or longer than 1 second for 100 pounds (445 newtons) of steady thrust

### Descent stage

The lower stage of the spacecraft has an octagonal prism shape, 3.9m (12.8ft) across and 2.6m (8.6ft) tall

### Egress platform

This allows the astronauts to crawl out of the ascent module before descending the ladder attached to one of the landing legs

### Landing legs

The four legs have large landing pads, and hold the Lunar Module 1.5m (4.9ft) above the lunar surface

### Fuel tanks

Two fuel (aerozine 50) tanks and two oxidiser (nitrogen tetroxide) tanks power the descent engine

### Ascent engine

Produces 3,500lb (16kN) of fixed thrust to launch the ascent stage off the descent stage, and enables it to rendezvous with the Apollo Command Module

### Storage compartments

A quadrant of compartments contain lunar surface experiments, spare batteries and equipment. On the Apollo 15, 16 and 17 missions, the Quadrant 1 bay carried the Lunar Roving Vehicle

### Descent engine

Can be gimbaled, and throttled between 10,125lb (45.04kN) and 1,050lb (4.7kN) of thrust to enable the craft to descend from lunar orbit, hover and land on the lunar surface

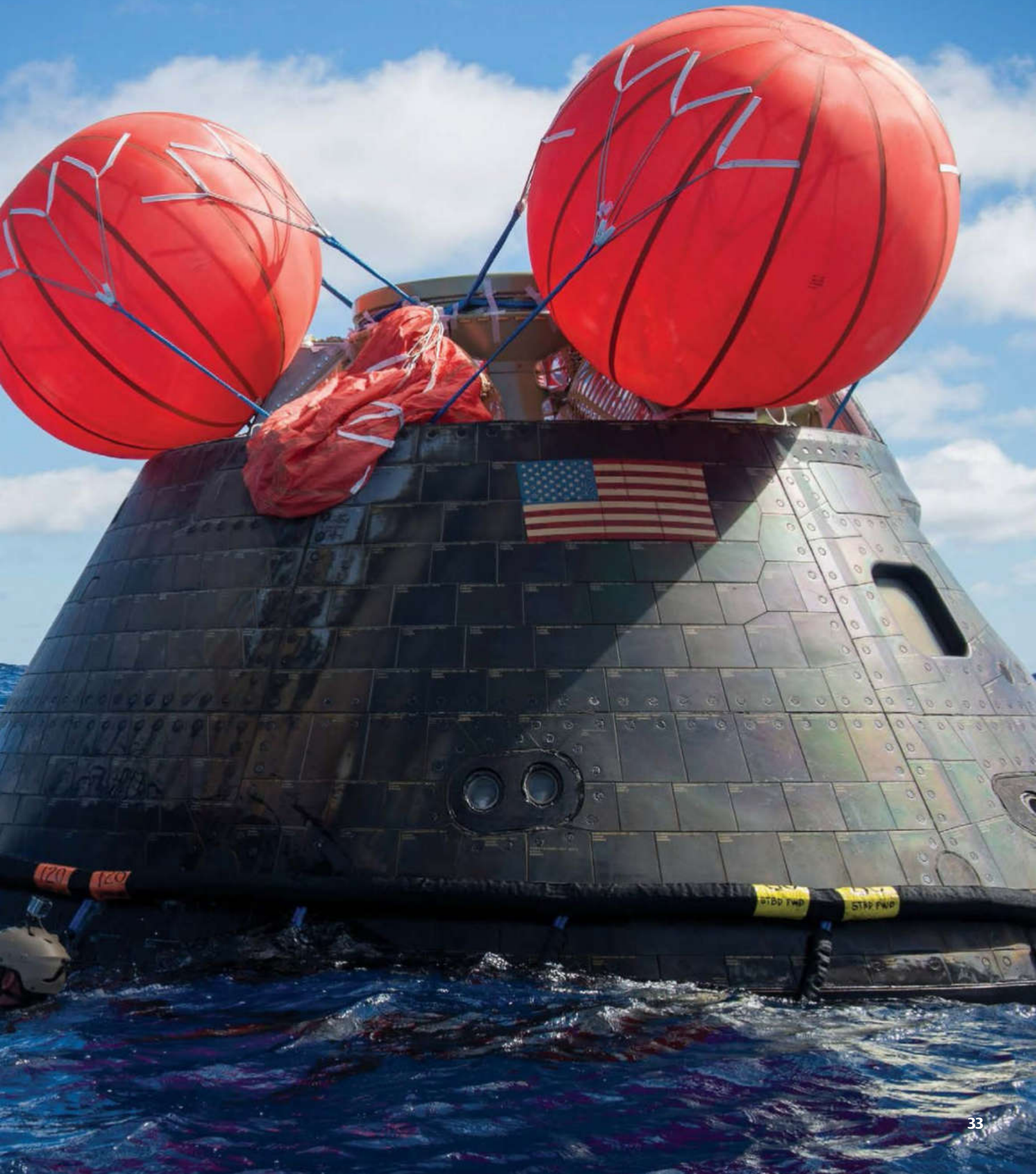


# 10 DARING SPACE RESCUES

From fearless spacewalks to death-defying descents to Earth, space is filled with stories of heroism that brought missions back from the brink of near-disaster









# 1 Apollo 13

**Disaster date:** 13 April 1970

**What happened:** A faulty oxygen tank turned the third manned mission to the Moon into an epic fight for survival

In April 1970, John Swigert, Fred Haise and James Lovell left Earth on a mission bound for the Moon. After 55 hours the crew took part in a live television broadcast back to Earth, but just nine minutes later, disaster struck.

Ground tests before the launch had revealed a problem with oxygen tank 2. It had been used previously on Apollo 10, but had been damaged and had undergone repairs. Before launch, it would not empty properly, so engineers used the internal heater to boil off the extra oxygen. Unbeknown to them, during the procedure, the on-off switch became welded shut.

The fault went unnoticed and during the flight the temperature inside the tank skyrocketed. When the crew stirred the tanks 56 hours into their mission, they didn't realise that the insulation on the electrical wires inside had melted. As the fans turned, the wires touched, shorting out and setting the insulation alight.

The astronauts heard a loud bang and felt the spacecraft rumble. Swigert contacted mission control and said the famous words, "Houston, we've had a problem here". The oxygen dials showed that one tank was empty and the level in the second was falling.

The crew had trained in simulations and remained calm, but tank one had also been damaged and their oxygen supply was rapidly running out. Before launch, the crew had practised using the Lunar Module as a lifeboat in case of emergencies. It carried enough oxygen and battery power for almost two days. With just a few minutes of power left the crew shut the Command Module down and transferred to the Lunar Module.

Mission control calculated that it would take two five-minute burns to loop Apollo 13 round the far side of the Moon and back towards Earth, but it would take several days to rescue them. The Lunar Module had only been designed to operate for two days. The temperature plummeted and the men had to drastically cut their water intake and they barely slept as they returned towards the Earth.

The Lunar Module was not heat shielded, so in order to re-enter Earth's atmosphere, the crew had to return to the Command Module. It'd never been switched off during a mission before but as they approached Earth, the astronauts managed to successfully power the module back on.

As the crew dropped through the atmosphere, communications cut out and mission control held its breath. Finally, they received confirmation that everyone was alright and the astronauts had splashed down safely in the Pacific Ocean.



## Mission timeline



### 8. Return home

**Time:** 142:40:45

Apollo 13 re-entered the atmosphere almost four days after the disastrous explosion, carrying the exhausted crew to a gentle ocean splashdown.

### 7. Assessing the damage

**Time:** 138:01:48

The damaged service module was released into space, and the crew were able to view the extent of the explosion for the first time.



"Mission control held its breath as the crew dropped through the atmosphere"



### Powering on

**Time:** 140:10:00

The Command Module was brought back online shortly before the crew reached Earth.

### 1. Lift-off

**Time:** 00:00:00

Apollo 13 was the third manned mission to the lunar surface, and the crew planned to explore the Fra Mauro region on the near-side of the Moon.



### 2. Television transmission

**Time:** 55:14:00

Shortly before the explosion, the crew took part in a live television broadcast back to Earth, showing viewers what life was like inside the module.







The Apollo 13 crew had to make use of the Lunar Module (on the left) in their fight for survival

## 6. Running repairs

**Time: 93:30:00**

After just a day and a half in the module, carbon dioxide levels rose dangerously high, and mission control had to invent a quick fix to replace the filters.



## 5. Emergency correction

**Time: 61:29:43**

The crew executed the first burn to swing Apollo 13 around the Moon and back towards the Earth.

## 4. To the lifeboat

**Time: 57:43:00**

As the remaining oxygen dwindled, the crew abandoned the Command Module and retreated to the safety of the Lunar Module, which had its own separate supplies.

## 3. "Houston, we've had a problem"

**Time: 55:55:20**

After the broadcast had ended, the crew were asked to stir the oxygen tanks. Tank two was faulty, and the procedure triggered a catastrophic explosion in the support module, venting their vital oxygen supply and taking the fuel cells offline.

Moon

## NASA's Apollo 13 report

“The Apollo 13 accident, which aborted man's third mission to explore the surface of the Moon, is a harsh reminder of the immense difficulty of this undertaking.

The total Apollo system of ground complexes, launch vehicle, and spacecraft constitutes the most ambitious and demanding engineering development ever undertaken by man. For these missions to succeed, both men and equipment must perform to near perfection. That this system has already resulted in two successful lunar surface explorations is a tribute to those men and women who conceived, designed, built, and flew it.

Perfection is not only difficult to achieve, but difficult to maintain. The imperfection in Apollo 13 constituted a near disaster, averted only by the outstanding performance on the part of the crew and the ground control team which supported them.

The Apollo 13 Review Board was charged with the responsibilities of reviewing the circumstances surrounding the accident, of establishing the probable causes of the accident, of assessing the effectiveness of flight recovery actions, of reporting these findings, and of developing recommendations for corrective or other actions. The Board has made every effort to carry out its assignment in a thorough, objective, and impartial manner. In doing so, the Board made effective use of the failure analyses and corrective action studies carried out by the Manned Spacecraft Center and was very impressed with the dedication and objectivity of this effort.

The Board feels that the nature of the Apollo 13 equipment failure holds important lessons which, when applied to future missions, will contribute to the safety and effectiveness of manned space flight.”



## 2 Rosetta/Philae

**Disaster date:** 12 November 2014

**What happened:** The ten-year mission to land a probe on a comet came close to failure when the harpoons designed to anchor the Philae lander did not deploy

The Rosetta spacecraft had chased comet 67P/Churyumov-Gerasimenko for over ten years, travelling 6.4 billion kilometres (4 billion miles) before coming into orbit on 6 August 2014. The next phase of the mission was to soft-land the Philae probe on to the surface so that it could sample the comet with its on-board laboratory.

The team aimed to slow the probe to one metre (3.3 feet) per second as it neared the surface, allowing its three legs to land gently on a flat patch of ground. Harpoons would then be deployed to bolt the lander to the floor. However, when Philae touched down it did not quite go as planned.

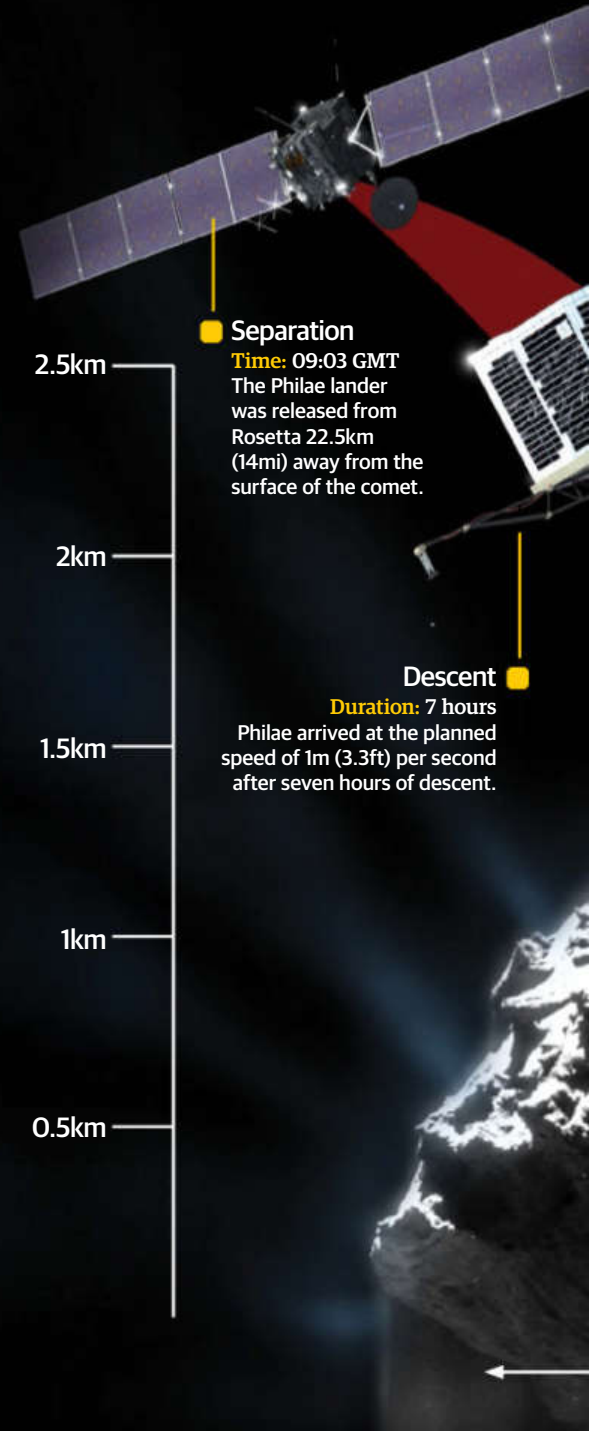
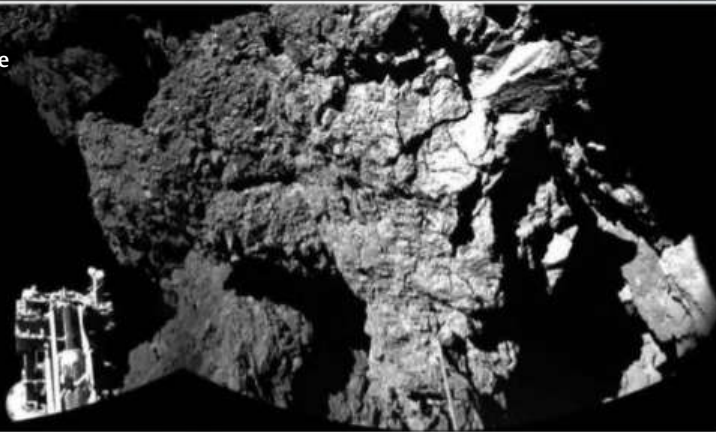
The anchoring harpoons did not fire and instead of landing safely, Philae bounced off, skipping twice like a stone before coming to rest. The surface of the comet was a dangerous combination of jutting rocks, boulders and plumes of gas and dust, and when Philae returned its first images, it became clear

that it was tilted sideways in the shadow of a cliff with one of its legs up in the air. Having bounced away from its planned landing site, scientists on the ground had no idea where the probe had eventually touched down.

Without enough sunlight, Philae was in danger of running out of battery and in its precarious position, any manoeuvre could knock it over completely or worse, propel it out into space. However, despite these problems, Philae completed its first set of science experiments, providing an incredible wealth of new data.

Philae's primary batteries ran down after 57 hours, at which point it entered hibernation mode. But before it went to sleep, scientists tried a bold rescue operation. They lifted the probe by four centimetres (1.6 inches) and rotated it by 35 degrees in the hope that with the solar panels repositioned, it might be able to wake up as the comet gets closer to the Sun.

With very little gravity on the comet, Philae is about the same weight as a paperclip, and this image captured by its camera reveals its precarious position



### Separation

**Time:** 09:03 GMT

The Philae lander was released from Rosetta 22.5km (14mi) away from the surface of the comet.

### Descent

**Duration:** 7 hours

Philae arrived at the planned speed of 1m (3.3ft) per second after seven hours of descent.

## 3 Spirit rover

**Disaster date:** 1 May 2009

**What happened:** After five years on the surface of Mars, NASA's Spirit rover became lodged in a sand trap

In the spring of 2009, NASA's Spirit rover was investigating a location on Mars known as Troy, but the ground was softer than it appeared. In 2006 Spirit's right front wheel had stopped working, and as the top layer of soil gave way, the stuck wheel churned the ground and Spirit started to sink.

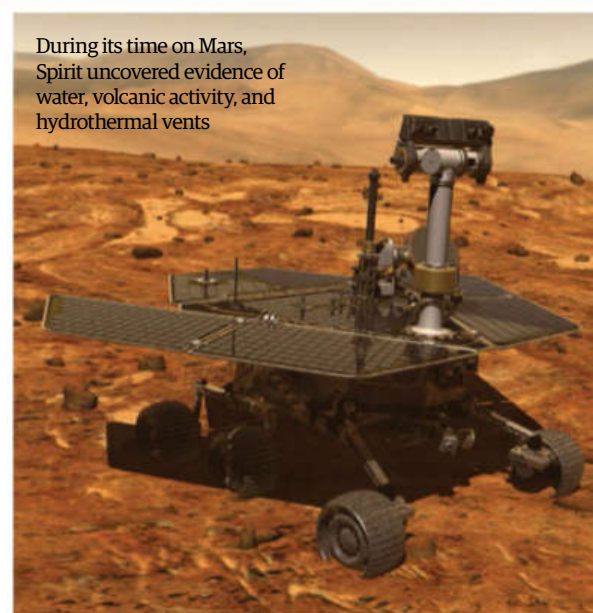
NASA engineers built a sandy testbed to replicate Spirit's predicament, and began testing different combinations of backwards driving and wheel wiggling to try to find the best way to free Spirit.

Attempts to rescue the rover began on 16 November 2009, but after three days it had only moved forwards by 12 millimetres (0.5 inches). The rear right wheel stalled repeatedly and after just a

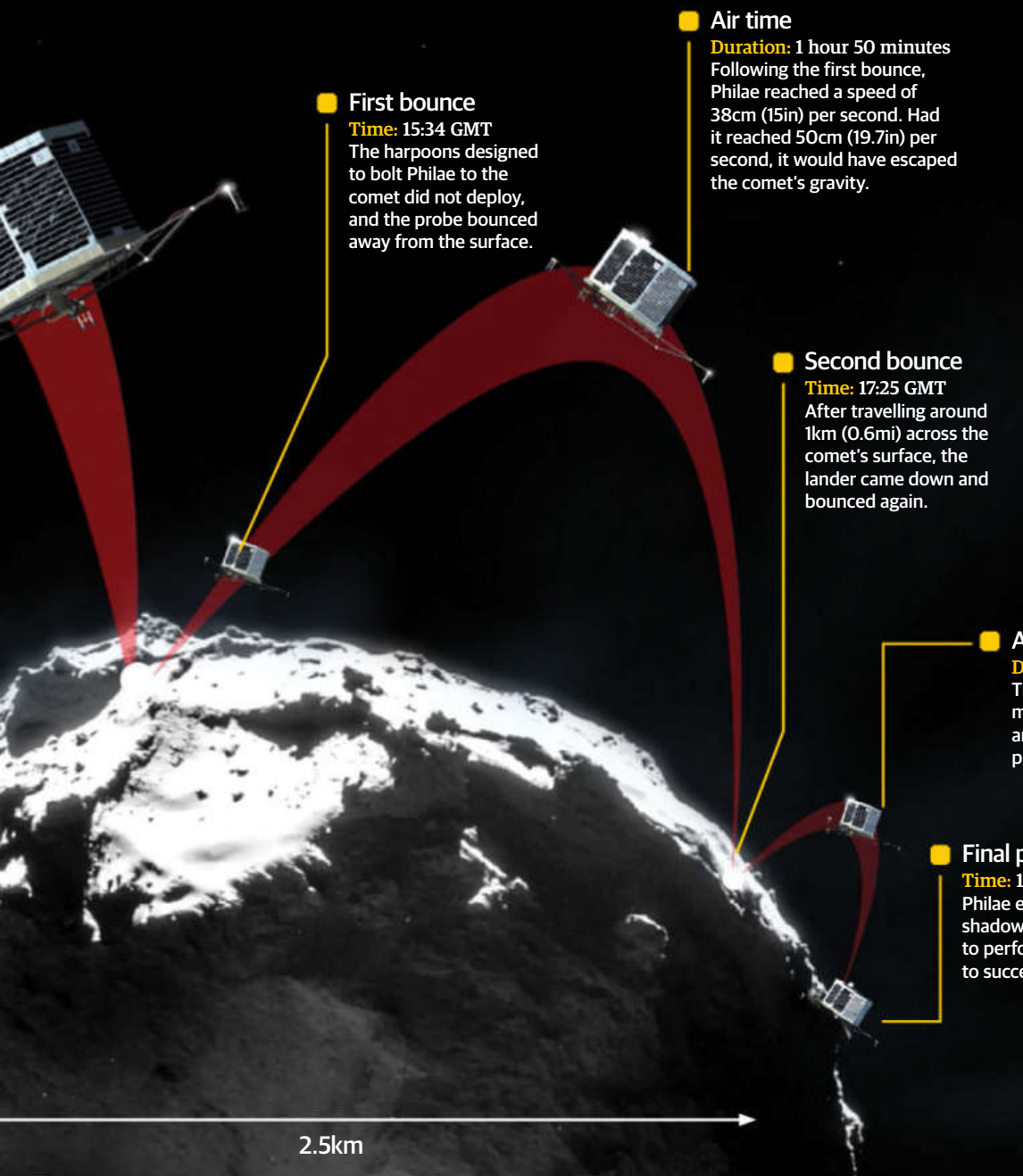
few attempts, it gave up altogether. With just four wheels remaining, and with winter fast approaching, the team feared that soon the rover would no longer be able to capture enough solar energy. They tried driving backwards, and managed to climb up for the first time, but progress was painfully slow and after eight months the rover was still trapped.

Winter eventually hit and Spirit entered hibernation, but unfortunately, contact never resumed. However, in the process of getting stuck churning up the soil, Spirit had released sulphates hidden beneath, revealing evidence of a nearby steam vent and providing new clues about the water cycle on modern Mars.

During its time on Mars, Spirit uncovered evidence of water, volcanic activity, and hydrothermal vents







**First bounce**  
**Time:** 15:34 GMT  
 The harpoons designed to bolt Philae to the comet did not deploy, and the probe bounced away from the surface.

**Air time**  
**Duration:** 1 hour 50 minutes  
 Following the first bounce, Philae reached a speed of 38cm (15in) per second. Had it reached 50cm (19.7in) per second, it would have escaped the comet's gravity.

**Second bounce**  
**Time:** 17:25 GMT  
 After travelling around 1km (0.6mi) across the comet's surface, the lander came down and bounced again.

**Air time**  
**Duration:** 7 minutes  
 The second bounce was much shorter than the first and saw Philae land in a precarious position.

**Final position**  
**Time:** 17:32 GMT  
 Philae ended up tilted sideways in the shadow of a cliff but nevertheless, was able to perform the science that enabled Rosetta to successfully complete its primary mission.

2.5km

## 4 Apollo 11

**Disaster date:** 24 July 1969

**What happened:** Buzz Aldrin and Neil Armstrong were almost stranded on the Moon after the switch that armed their ascent engine broke

The Moon landing was one of the most monumental days in human history, but there were some tense moments along the way. The descent was challenging, and amid problems with communications and the on-board computer, Armstrong and Aldrin overshot their landing zone. They eventually touched down with less than 30 seconds of fuel remaining.

After their historic moonwalk, the two astronauts returned to the lander, but in the process one of their life support backpacks nudged the switch that armed the ascent engine and snapped it off. Without it, they wouldn't be able to return to the waiting orbiter. Ground control quickly replicated the fault on a mockup of the module on Earth, and set about finding a way to flick the switch using any available objects. Luckily, the astronauts were carrying pens, so Aldrin was able to use one to push the switch, arming the engine and saving the day.



The Spirit rover became stuck in soft soil at the edge of a crater, and despite months of rescue attempts was unable to break free



Space Shuttle Endeavour carried seven crew members to Hubble and after five separate spacewalks, the telescope was fixed



# 5 Hubble Space Telescope

**Disaster date:** 20 May 1990

**What happened:** The iconic Hubble Space Telescope almost became one of science's biggest mistakes when it was launched into space with a faulty mirror

The Hubble Space Telescope has captured some of the most iconic images ever taken of outer space, but it started out with a major fault. The project had cost billions of dollars and carried a meticulously polished 2.4-metre (7.9-foot) mirror weighing just over 800 kilograms (1,800 pounds). Free from the interference of Earth's atmosphere, Hubble was expected to return high-resolution images but after the first images were returned just a few weeks later, it became clear that something was wrong.

The primary mirror had a flaw known as a spherical aberration; the edges were too flat, which meant that the light was not properly focused, causing a fuzzy halo to appear in every image. There was public outcry, and NASA came under attack for wasting money on a scientific disaster.

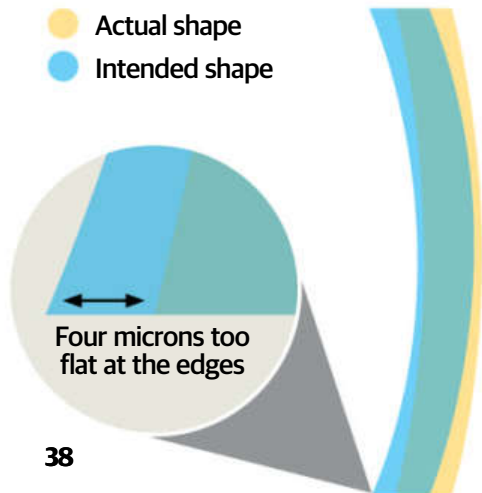
So, in 1993, NASA attempted to save the ailing space telescope. Seven crew members carried with them the Corrective Optics Space Telescope Axial Replacement (COSTAR). It was made up of five pairs

of mirrors that, when installed in front of the Faint Object Spectrograph, the Goddard High Resolution Spectrograph and the Faint Object Camera, would work like a pair of glasses to bend the light, bringing it into focus. They also took the Wide Field Planetary Camera 2, which included its own corrective optics, and boosted Hubble's ultraviolet vision.

The astronauts spent 11 months training and practised the fiddly procedures over and over again inside a special water tank. The mission was a resounding success but during the final stages, while changing some insulation, a tiny screw floated away. Fearing that it could dent the new mirrors, the crew had to use the Shuttle's arm to capture it.

## The mirror flaw

- Actual shape
- Intended shape

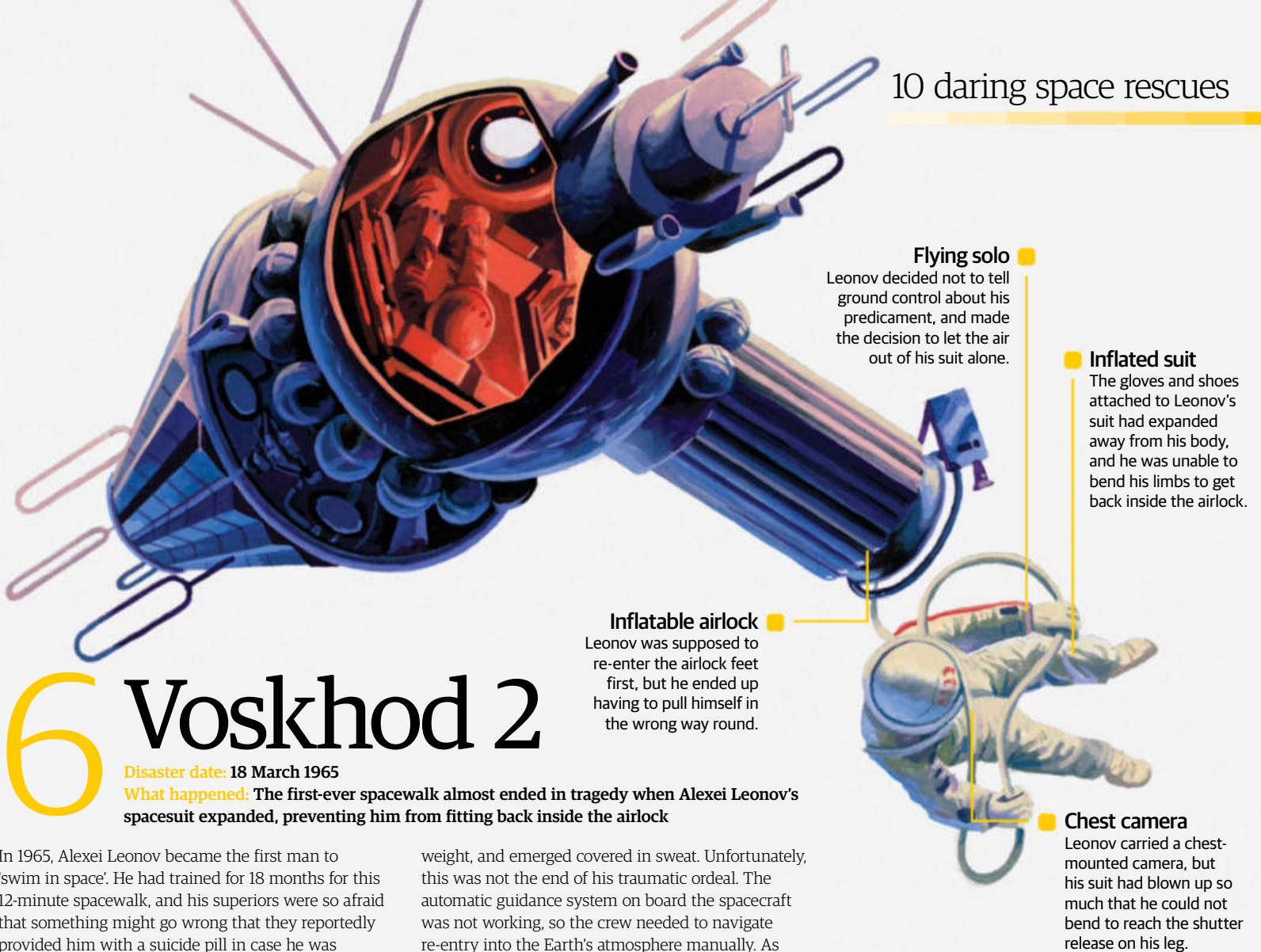


## Spot the difference



This before and after image of the nucleus of the M100 galaxy reveals the full extent of Hubble's mirror fault





# 6 Voskhod 2

**Disaster date:** 18 March 1965

**What happened:** The first-ever spacewalk almost ended in tragedy when Alexei Leonov's spacesuit expanded, preventing him from fitting back inside the airlock

In 1965, Alexei Leonov became the first man to 'swim in space'. He had trained for 18 months for this 12-minute spacewalk, and his superiors were so afraid that something might go wrong that they reportedly provided him with a suicide pill in case he was unable to re-enter the spacecraft.

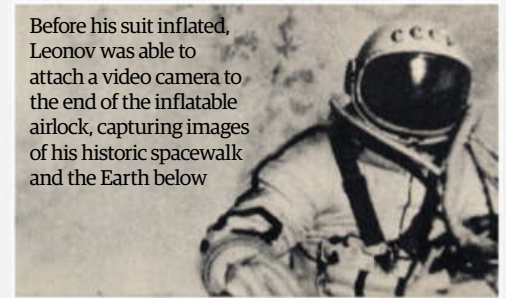
By the time Leonov had completed his spacewalk, the air inside his suit had expanded in the vacuum of space. Moving became difficult, and when he tried to return to the airlock he realised that he could no longer fit inside. Leonov was running out of time and realising the severity of his situation, he tried something brave. He began to deflate his suit, risking his oxygen supply by releasing the gas into space.

He managed to squeeze back into the airlock but in the process lost six kilograms (13 pounds) in body

weight, and emerged covered in sweat. Unfortunately, this was not the end of his traumatic ordeal. The automatic guidance system on board the spacecraft was not working, so the crew needed to navigate re-entry into the Earth's atmosphere manually. As they descended the craft began to spin. They veered off course and came down in the icy wastelands of the taiga forests of Siberia.

The spacecraft eventually crash-landed in an area that was so inaccessible that the rescue helicopter was unable to land. Instead, they dropped supplies and the cosmonauts had to spend two nights in the forest with an open hatch, braving bears, wolves and the elements, before the rescue team accompanied them as they skied to the nearest landing point for evacuation.

Before his suit inflated, Leonov was able to attach a video camera to the end of the inflatable airlock, capturing images of his historic spacewalk and the Earth below



# 7 ISS helmet malfunction

**Disaster date:** 16 July 2013

**What happened:** An ISS spacewalk was abruptly cut short when Luca Parmitano's helmet started to fill with water

During a spacewalk on the International Space Station, Luca Parmitano realised that something wasn't right. He could feel water creeping across his communications cap, and it soon became clear that he needed to go back to the airlock.

As Parmitano tried to climb back, the Sun set, plunging him into almost total darkness. He later told us, "It's a black like nothing you can experience on Earth." Guided only by a 30-centimetre (12-inch) ring of light from his helmet and with water

covering his eyes and nose, Parmitano had to navigate across a 'no-touch zone'. "I was upside down with no light, no eyesight because my eyes were covered, I had water in my nose and I tried to call the ground and Chris, but neither one could hear me."

Parmitano decided to return to the airlock unaided and five minutes later he was inside. "The next thing I knew Chris was squeezing my hand trying to get a response and my response was to squeeze as hard as I could to give him the okay."



During a spacewalk on the ISS, water started to build up inside Luca Parmitano's faulty helmet, clinging to his eyes and nose



# 8 Progress-Mir collision

**Disaster date:** 25 June 1997

**What happened:** The crew of Mir faced catastrophe as a bus-sized supply freighter punched a hole in the Russian space station

In 1997, Russian cosmonaut Vasily Tsibliev was in charge of docking the supply freighter Progress with the Mir Space Station. It was his job to guide Progress in, using an on-board camera to navigate. However, the slow pictures made judging the speed of the craft difficult and, as Progress headed towards Mir, it began to move too fast.

Cosmonaut Aleksandr Lazutkin saw the craft approaching and sounded the alarm. Even though Tsibliev had fired the braking rockets, it was too late and Progress slammed into Mir's Spektr module, crashing through the solar array and tearing a hole in the hull.

The crew worked rapidly to cut the connections to the damaged module. Pressure inside stabilised and the immediate danger was over, but the impact had set Mir spinning wildly, preventing the remaining solar panels from facing the Sun.

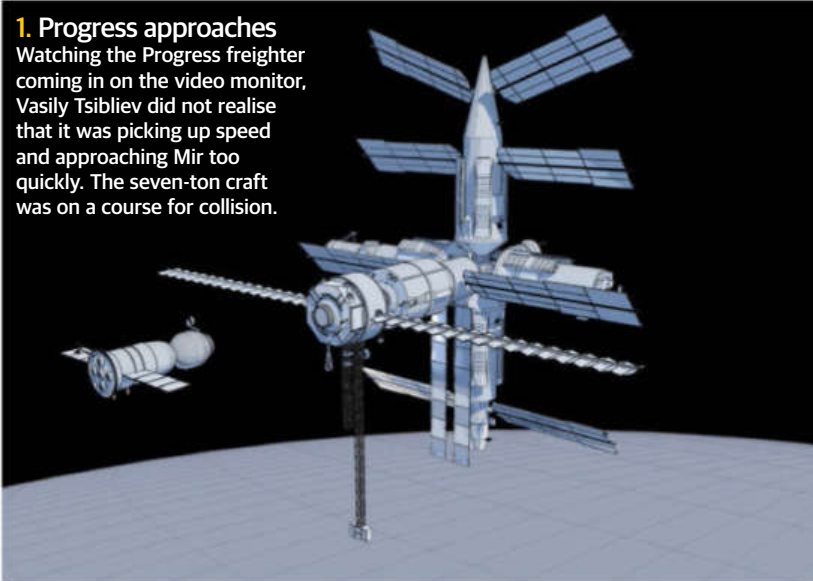
Working together with Tsibliev, who was now at the controls of the docked Soyuz, astronaut Mike Foale shouted instructions to fire the thrusters to bring the spin under control. As they passed over the sunny side of the Earth, they managed to charge the batteries and to the relief of all, the space station came back to life.



The Progress freighter slammed straight into the Spektr module on Mir. The solar panels were crippled and a hole was punched through the hull

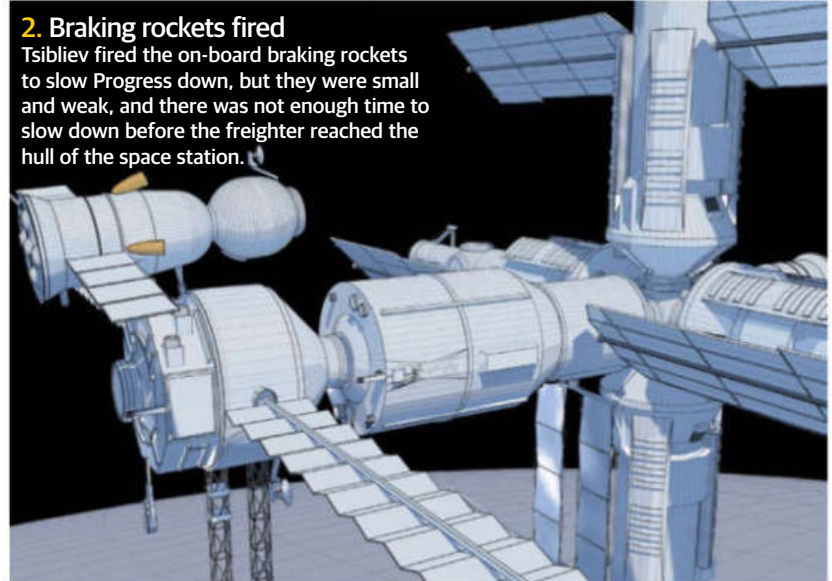
## 1. Progress approaches

Watching the Progress freighter coming in on the video monitor, Vasily Tsibliev did not realise that it was picking up speed and approaching Mir too quickly. The seven-ton craft was on a course for collision.



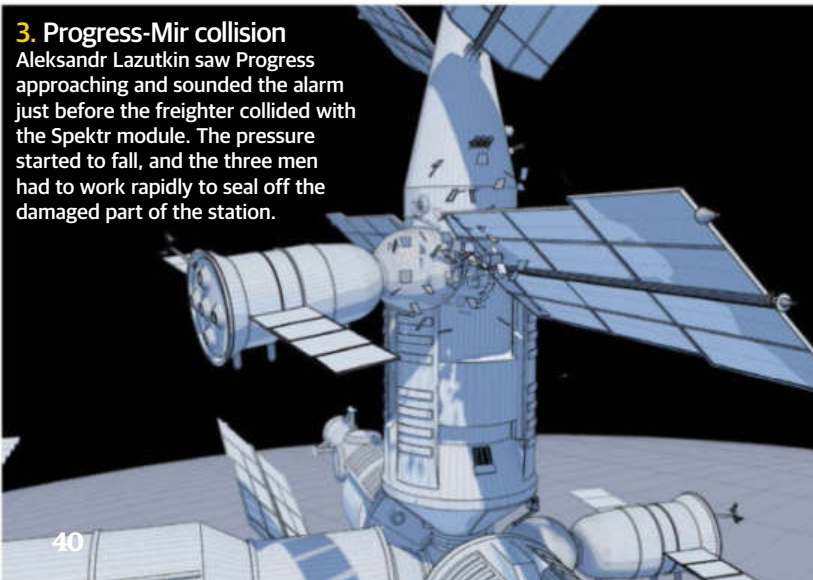
## 2. Braking rockets fired

Tsibliev fired the on-board braking rockets to slow Progress down, but they were small and weak, and there was not enough time to slow down before the freighter reached the hull of the space station.



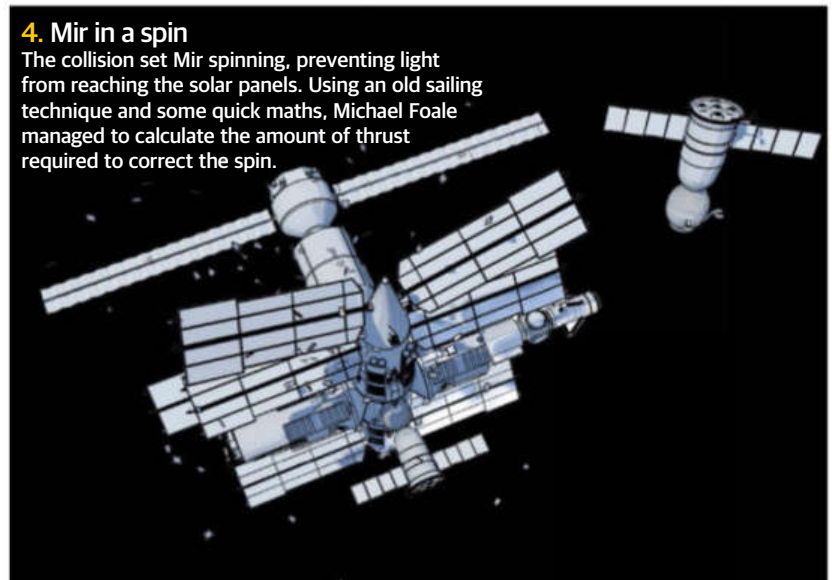
## 3. Progress-Mir collision

Aleksandr Lazutkin saw Progress approaching and sounded the alarm just before the freighter collided with the Spektr module. The pressure started to fall, and the three men had to work rapidly to seal off the damaged part of the station.



## 4. Mir in a spin

The collision set Mir spinning, preventing light from reaching the solar panels. Using an old sailing technique and some quick maths, Michael Foale managed to calculate the amount of thrust required to correct the spin.





# 9 Space Shuttle Discovery

**Disaster date:** 26 July 2005

**What happened:** During the launch of the first Space Shuttle flight after the 2003 Columbia disaster, the heat shielding on the underside of the craft was damaged

In 2005, NASA's Space Shuttle Discovery travelled to the International Space Station to deliver supplies and equipment, but during launch the craft sustained some damage. Several chunks of insulating foam broke away from the Shuttle, and some of the ceramic gap fillers that stop the heat shield tiles from rattling managed to wriggle free. Engineers were concerned that these uneven bumps would cause turbulence as the craft re-entered Earth's atmosphere, and projected that the damage could increase heating by up to 30 per cent, potentially putting the lives of the crew in danger.

Just two years earlier, Space Shuttle Columbia had broken up on re-entry following damage to its heat shields, tragically ending the lives of its seven crew members. After this tragedy, ground control was not happy to allow the Discovery crew to return to Earth until the damage had been fixed.

A repair mission was included during the third and final spacewalk, but nothing like it had ever been attempted before. The underside of the Shuttle was fragile and astronauts had never been allowed so close to the heat shielding tiles before. As a consequence, no handrails had been built in for support, so astronauts Steve Robinson and Soichi Noguchi had to ride on the International Space Station's Canadarm2 robotic arm to reach the damaged area.

Robinson was to perform the historic repair and he carried a pair of forceps and a saw with him, in case the ceramic fabric was difficult to remove. But in the end he found it simple enough to ease them out with his fingers. As he triumphantly removed the second piece he said, "it looks like this big spaceship is cured". The Shuttle was later cleared for re-entry, and returned safely to Earth on 9 August 2005.

"Ground control wouldn't let Discovery return to Earth until the problem was fixed"

The crew had to fix the heat shield problems before returning to Earth



NASA astronaut Steve Robinson captured this close-up image of Discovery's heat shields as he performed the vital repairs

## 10 Liberty Bell 7

**Disaster date:** 21 July 1961

**What happened:** One of the first-ever suborbital space flights almost ended in disaster when the escape hatch blew open prematurely, flooding the capsule in the middle of the ocean

Gus Grissom had been on a 15-minute suborbital flight and had splashed down in the Atlantic Ocean. His capsule, Liberty Bell 7, was fitted with a new explosively activated escape hatch at the side but as he waited for the helicopter, it burst open and water flooded in. Grissom escaped as the capsule started to sink but he was left floating in the open ocean. He had also forgotten to close the oxygen inlet to his suit and water was trickling in, weighing him down.

Unaware of his immediate peril and thinking that the spacesuit would keep Grissom afloat, the helicopter pilot attempted to rescue the sinking capsule first. But Liberty Bell 7 kept refilling as the waves swelled, and the helicopter could not take the strain.

After a tense four minutes and with Grissom close to drowning, the sinking capsule was abandoned to the waves, and a second helicopter was called to pluck the exhausted astronaut from the water.



The hatch on Liberty Bell 7 flooded with water each time the waves swelled, and the helicopter's engine almost cut out



With the first helicopter in a bad way, a second rescue pilot had to be called to pull Grissom from the Atlantic Ocean



# SEARCH FOR LIFE

The five most important people in the search for extraterrestrial life



#### Dr John Mather

Dr Mather is a senior project scientist on NASA's James Webb Space Telescope. This giant space observatory will launch in 2018 and will aid in the hunt for potentially habitable planets outside our Solar System



## Search for life

### Dr Jerry Ehman

Dr Ehman, now retired, is an American astronomer. He previously worked for SETI and in 1977 he discovered the famous Wow! signal, which just might have been our first contact from an intelligent alien race

### Dr John Elliott

Involved with SETI since 1999, Dr Elliott's research includes working out how we'd decipher, and respond to an alien signal. He is a Reader in Intelligence Engineering at Leeds Metropolitan University in the UK

### Dr Seth Shostak

As senior astronomer at the SETI Institute in Mountain View, California, Dr Shostak is actively involved in the hunt for intelligent life. He is also a writer and hosts the *Big Picture Science* radio show

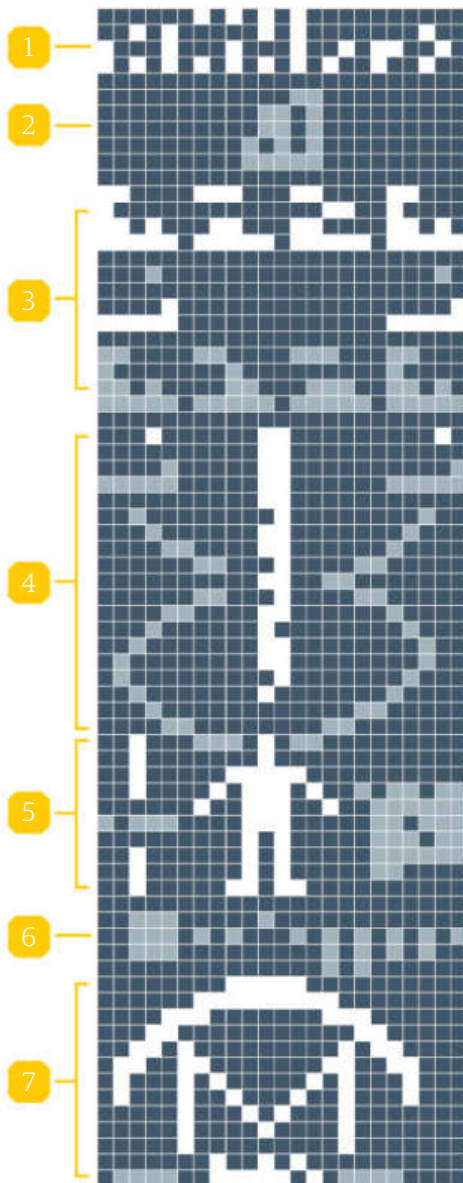
### Dr Jennifer Eigenbrode

Dr Eigenbrode is a biogeochemist at NASA who specialises in astrobiology. She's looking for signs of life in the smallest places, including looking for biosignatures in rocks and ice on Mars through the Curiosity rover



## The Arecibo message

On 16 November 1974, astronomers including Dr Frank Drake and Carl Sagan devised a message to send into the distant reaches of space. The message was intended to show the possibilities of communication with a potential intelligent race, rather than actually attempting to make contact.



### 1. Numbers

The numbers one to ten written in binary.

### 2. DNA

These represent the atomic numbers of the elements that make up DNA.

### 3. Formula

These are the formulas for the sugars and bases in DNA.

### 4. Double helix

A graphic of the double helix structure of DNA.

### 5. Population

A figure of a human and Earth's population.

### 6. Solar System

A graphic depicting the Solar System.

### 7. Dish

A graphic of the Arecibo dish and its dimensions.

Every month we hear of incredible new exoplanets in planetary systems seemingly like our own, and we learn more in the search for past or present microbial life as missions like Curiosity gain worldwide attention, but for some reason the notion that we might be just one intelligent race among many is yet to receive much support from the public at large.

Many people today still seem to have the same opinion that was prevalent in the mid to late 20th Century, that aliens are something that belong only to the realm of science fiction, but this is in the face of overwhelming evidence to the contrary. With every passing year, every new discovery of an exoplanet, every observation of frozen or liquid water on other bodies in the Solar System, it becomes harder and harder to argue that we are alone in our galaxy, let alone the entire universe.

In fact, it's a position that even notable astronomers are taking up. "We can't be the only instance of a race, we just can't be," said the late Sir Patrick Moore when talking to us in 2012, and he is joined by many others around the world who are coming around to the realisation that to think humanity is the only instance of intelligent life is implausible, ignorant and just plain naive.

For about half a century we have begun to seriously consider the possibility that we are not alone, and to prove this hypothesis scientists have focused on three areas of research, each equally capable of becoming the first to discover life outside of the confines of Earth. Throughout this feature we've spoken to the five most important people within these fields to find out what progress they're making in the search for life.

The first is the Search for Extraterrestrial Intelligence, or SETI, which is a privately funded

international endeavour to discover signals from an alien race drifting through the cosmos. Next is the search for exoplanets (worlds outside our Solar System), an area of research that has only gained credence in the last couple of decades. The field of planet hunting may be young, but it is already providing us with fascinating results that may soon help us find an exoplanet just like Earth. The final area of research is the search for microbial life, fossilised or alive, on other worlds inside our Solar System. Until now this has largely focused on Mars, but places like Europa and Titan could also prove fruitful to explore.

The oldest of the three areas of research is SETI, using antennas around the world to look for alien signals. In 1959, Giuseppe Cocconi and Philip Morrison, two physicists from Cornell University in the USA, suggested for the first time that it might be possible to communicate with another intelligent race among the stars using microwave radio. "The probability of success is difficult to estimate," they wrote in the journal *Nature*, "but if we never search, the chance of success is zero."

At around the same time a young radio astronomer named Frank Drake came to the same conclusion, and in the following year he used a 26-metre (85-foot) telescope in West Virginia, USA, to conduct the first search for alien signals outside our Solar System. He found nothing, but his research (including the Drake equation, which estimates that the chances of life elsewhere in the universe is almost a certainty) sparked an interest around the globe that remains prevalent to this day. It was in fact the Soviet Union in the Sixties that first dominated SETI, observing huge portions of the sky at once. They were sure that there would be many advanced civilisations emitting

"We can't be the only instance of a race, we just can't be" **Sir Patrick Moore**





# He'll be the person to know first

## Dr Seth Shostak

### How do you guys analyse incoming data at SETI?

The data analysis is all pretty automatic. Unless there's a signal that's looking very promising, and that only happens every couple of years, then you don't actually deal with the data processing. The algorithms in the software analyse them and do rather simple tests to try to prove if it's really ET, or if it's AT&T - interference from a telecommunications satellite or whatever.

### Are there protocols in place for announcing the discovery of an alien signal?

We've been worrying about the protocols about what to do if we find a signal. We've rewritten them and they're all very nice in a nice little document, but the reality is that nobody's going to pay a whole lot of attention to protocols if we pick up a signal. And we know that because we've had false alarms, like in 1997 when for almost a day it looked like we had a signal that was the real deal. And did people stick to protocols and say, 'well, we've got to notify these people and those people?' No! None of that happened. It was completely chaotic, which it would be.

### What's the next step after the discovery of a signal?

If you get a signal that looks like it might be ET on the line, the first thing you do is to spend an awful lot of effort trying to verify that, maybe several days. But in all that time while you're doing this there's no policy of secrecy, so lots of people know you've got an interesting signal. In 1997, when we had this promising signal there were no men in black, the government hadn't the slightest interest in any of it, but the media did and they started calling me up.

### What happens next?

After that, every telescope in the world would be aimed in the direction of the signal to try to find out how far

away it is and whether there are planets there. Keep in mind that the instruments [being] used by SETI are not capable of [deciphering] messages. You're getting the bottle [signal] without the message in it, but at least you've got the bottle so you know that somebody's trying to say something.

### What would become of SETI?

There would suddenly no longer be a fight to try to get enough money to keep doing the SETI experiment. There would be enough money to build much bigger instruments and go back and possibly find any message. I'm sure there would be a message there. I think that immediately SETI would be vaulted from sort of a backburner niche science experiment to something that many, many people were doing. That's exactly what happened with the discovery of planets around other stars. There were a couple of guys doing it in the world, and suddenly it became an industry. That's what would happen with SETI.

### Would we understand the message?

My guess is they're likely to be hundreds of thousands of years, maybe more, beyond us. And for us to understand the information content of their transmissions is probably asking too much. But at least you'd know they were there, and that's really the idea, isn't it? You would know that what we have here on Earth is pretty nifty, but it's not a miracle.

### Are you confident we'll find a signal?

I bet everyone here a cup of coffee that we'll find aliens within two dozen years.

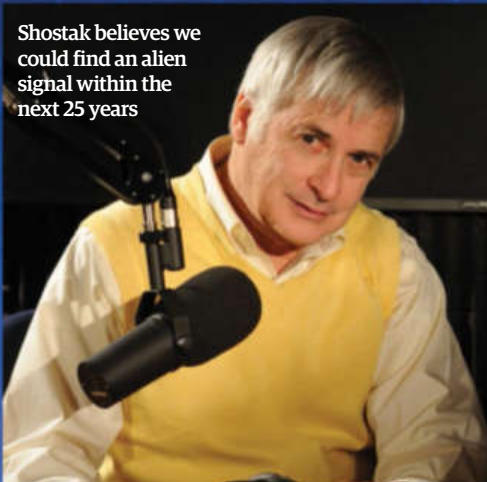


## BIO

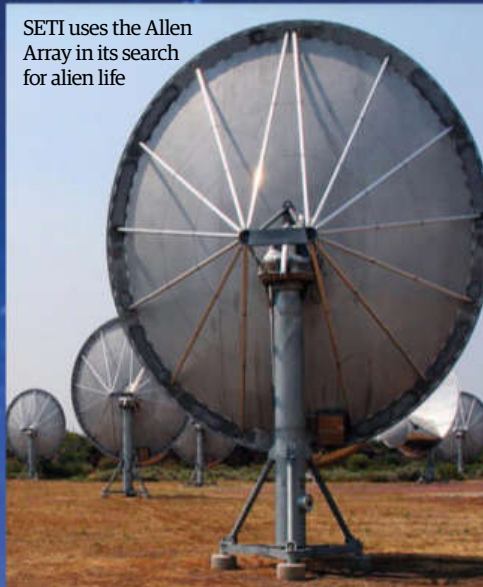
### Dr Seth Shostak

Dr Shostak is the senior astronomer for the SETI Institute in Mountain View, California. He is actively involved in the hunt for alien signals. He is also a writer and hosts a weekly science radio show.

Shostak believes we could find an alien signal within the next 25 years



SETI uses the Allen Array in its search for alien life



"In 1997, for almost a day it looked like we had a signal, that was the real deal"



# The next great planet hunter

## Dr John Mather

### BIO

#### Dr John Mather

Dr Mather is a senior project scientist on the James Webb Space Telescope. He is also a senior astrophysicist in the Observational Cosmology Laboratory at NASA's Goddard Space Flight Center.

#### What's your role on the James Webb Space Telescope (JWST) project?

I'm the senior project scientist, which means that I work with the project management and engineering teams to define the mission requirements to make sure that they are correctly implemented, and with the scientific teams to make sure we have understood the scientific opportunities and their implications for what should be built to enable spectacular discoveries.

#### What work will you be doing in the coming years, and post launch in 2018?

I'll be continuing my role as senior project scientist to make sure our mission realises its potential. Post launch I anticipate writing observing proposals and working with colleagues to write up the results. I hope to be lucky and find something that's a great surprise.

#### How will JWST aid in the hunt for exoplanets?

We have two main ways. First, we look at planets directly with coronagraphs in three of the four instruments. Coronagraphs block out the direct starlight so we can look for planets orbiting nearby, which is primarily valuable for large and young planets. Second, we watch a star get fainter when a planet goes in front of or behind its star [which is known as 'transiting']. We can get amazing details about the planets and their atmospheres from this data.

The Kepler mission has given us thousands of candidate planets [using the transiting method] and they are all interesting. If we can get a really good target there is the possibility that we could find signs of water around a large

version of Earth, and then we would think such a planet could harbour life.

#### Could a separate star shade be flown near the James Webb Space Telescope to block out the light of distant stars and help find planets?

Yes, of course! Our team considered star shades in the very early days of conceiving the mission, but the technology was clearly not ready in 1996. Now, much work has been done by university groups and aerospace firms like Northrop Grumman and Lockheed Martin, and we know quite well how to design such a shade. In my opinion it could be done for a budget that would be worth the fabulous planet measurements that could be made. Either a star shade could be built to fly near to JWST, or a star shade could be made to work with a new telescope. Both are difficult but possible.

#### Do you think we'll find an Earth-replica before JWST launches in 2018?

Yes, I think the Kepler mission will find planets a lot like Earth, in the sense of being the right size and temperature, orbiting stars a lot like the Sun. But we probably won't know much about their properties, so we won't be able to say they are 'exactly' like Earth.

#### Do you think we will ever make contact with an intelligent alien race?

I don't think we will make contact with an intelligent extraterrestrial race any time soon. I think they exist but they are really hard to find and probably far away. On the other hand, I really do think it's worth trying! We already have technology that could send detectable signals across our whole galaxy, but it would only work if somebody on the other end knew how to receive them. Now our job is to guess how to eavesdrop on those other civilisations, if they exist.

"They exist but they are really hard to find and probably far away"

The James Webb Space Telescope is set to launch in 2018



# Did he already make contact?

## Dr Jerry Ehman

### What are you working on at the moment?

I am retired. I enjoy bowling and golf and am involved in church activities. I unvolunteered from the Ohio State University Radio Observatory back in 2008, so I am no longer actively working much in SETI.

### What were you doing at the time you discovered the Wow! signal?

I was a professor in Management Science at another university in Columbus, Ohio. I was also a volunteer at the Ohio State University Radio Observatory (OSURO).

### What was the Wow! signal?

It was a strong narrowband signal from an unknown object. The distance to that object could not be determined.

### Did you believe the Wow! signal was a sign of extraterrestrial intelligence?

Since all of the possibilities of a terrestrial origin have either been ruled out or seem improbable, and since the possibility of an extraterrestrial origin has not been able to be ruled out, I must conclude that an extraterrestrial intelligence *might* have sent the signal that we received as the Wow! source.

### Where do you think it came from?

After some analysis and thought, it became quite obvious that this signal came from some object a large distance away from the Earth (well beyond the distance of the Moon).

### Could we have learned more about the signal if more resources had been available?

At the time, personal computers didn't exist. If we had today's equipment, much more could have been learned. For example, it might have been possible to detect the modulation [information] components of the signal.

### Do you think we'll detect a signal from an intelligent race in the coming years?

I'm certainly hopeful.

### Will we ever contact alien life?

Contact is less likely than the detection of a signal, although I'm also hopeful that contact will occur some time in the next billion years or so.

### Do you think life is out there?

Absolutely!



### BIO

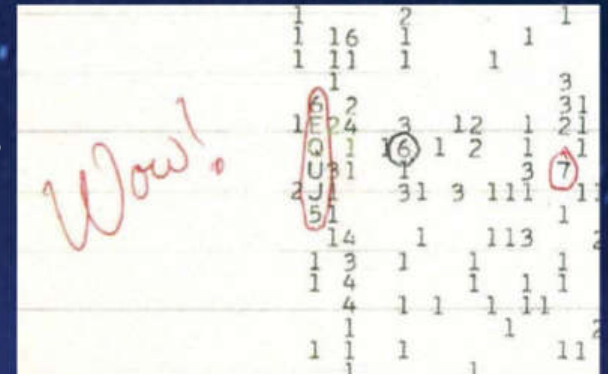
#### Dr Jerry Ehman

Dr Ehman, now retired, is an American astronomer. He holds a PhD in astronomy from the University of Michigan. In 1977, while working on the Big Ear radio telescope at the Ohio State University, he discovered the famous Wow! signal.



## The Wow! signal

One of the most famous instances of the detection of possible alien life was a radio signal that has been dubbed the Wow! signal, owing to Jerry Ehman (above) circling the signal in excitement. Ehman discovered the signal on 15 August 1977 while working on a SETI project. The circled code, '6EQUJ5', indicated an increased intense signal that seemingly came out of nowhere.



huge amounts of power that would be easy to spot, but this was not so.

It was widely believed that SETI had a good chance of success, though, so in the Seventies NASA threw its hat into the ring. It established SETI programmes in California at its Ames Research Center in Mountain View and the Jet Propulsion Laboratory in Pasadena to look for signals around stars like our Sun or otherwise. In the mid-Nineties, however, funding was cut, and the SETI Institute was forced to go it alone.

SETI uses a number of antennas and arrays around the world, such as the Allen Telescope Array in California, to observe distant stars and discern whether they are emitting any artificial signals produced by an intelligent race. Within minutes of observing a star they have an answer, but to this day they have yet to find any conclusive evidence of extraterrestrial intelligence. Undeterred, workers at

SETI continue to search for signs of life, and they're extremely confident that they will find something.

To aid in SETI's study, the hunt for habitable exoplanets might allow us to find worlds where life could reasonably be thought to reside. Finding habitable exoplanets that SETI can study for signals is something that will prove of great importance. Of course, planet hunting itself is an area of astronomy that is not even two decades old - the first exoplanet was not discovered until 1995. But while planet hunting might still be in its infancy, the results we have obtained from just a handful of telescopes are astounding. NASA's Kepler space telescope, which launched from Cape Canaveral in March 2009, has found thousands of planet candidates in barely four years of operations, and some of these offer tantalising hints of being habitable.

But Kepler is looking at just a tiny portion of our giant Milky Way, which in turn is relatively

small in the grand scheme of the universe. Based on data from Kepler, astronomers at the Harvard-Smithsonian Center for Astrophysics estimated in January 2013 that there were at least 17 billion Earth-sized exoplanets in the Milky Way. That's not a typo; billion, not million. Consider that there are about 100 billion galaxies in the known universe, and things start to get really exciting. Is it really possible that, out of 1.7 trillion trillion potential planets in the 13.7 billion-year-old universe only one, Earth, had the necessary conditions to produce intelligent life? Many leading scientists believe this to be unlikely.

Kepler, however, can only reveal very basic data about an exoplanet, including its size, mass and orbit. Future telescopes, like NASA's James Webb Space Telescope, will allow us to study these planets in even more detail. This giant space observatory, which will launch in 2018, might be able to directly image exoplanets and even reveal the composition of





Dr Eigenbrode believes that if alien life exists beyond Earth it is most likely microbial

# Looking for life in small places

**Dr Jennifer Eigenbrode**

## What's your role at NASA?

I am a research scientist at NASA Goddard Space Flight Center. My studies focus on understanding the sources, alteration, and preservation of organic molecules in geological materials on Earth and Mars. I am a participating scientist on the Mars Science Laboratory [Curiosity] and a collaborator for the Sample Analysis at Mars [SAM] instrument suite that can detect organics in Gale Crater sediments.

## Do you think we'll find evidence of past or present life on Mars?

I think Mars may have harboured life in the past. The conditions of Mars 3.5 billion years ago were probably similar to the conditions of Earth. Both were likely habitable. If past life did exist on Mars, then there should be a record of it in the sediments. If life didn't exist on Mars, we may expect to find meteoritic or geological organic matter. Hopefully, we'll find preserved organics in the surface sediments at Gale Crater where the MSL rover is exploring. Exploration by the ESA/NASA ExoMars rover [due to land in 2018] and the NASA Mars 2020 rover will be valuable in furthering our understanding of organic preservation on Mars.

## Where else could we find organics in the Solar System?

Today, we find evidence of organics in interstellar gas particles, meteorites, comets and in some planetary atmospheres [such as methane on Mars and Titan]. There is every reason to suspect that organics have

been distributed all over the Solar System. What we do not understand is what has happened to these organics since their initial distribution. What processes have altered them? Has life tapped their carbon and energy to support extraterrestrial ecosystems?

## Do you think the Allan Hills 84001 meteorite contained fossilised life?

It was the publication of the suspected microfossils in this Martian meteorite that energised the field of exobiology [now astrobiology]. As much as I wanted to believe 84001 contained Martian microfossils, I was never convinced.

## Will we find more complex forms of life in the Solar System?

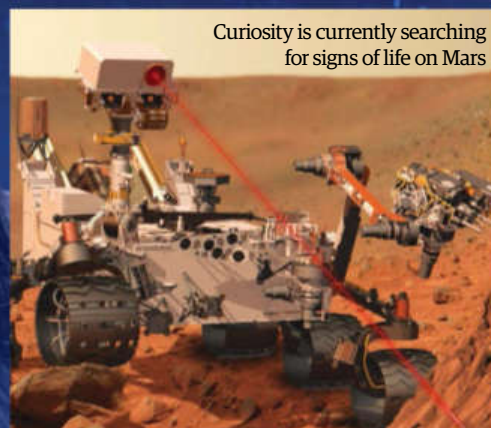
If life exists elsewhere in the Solar System, it is most likely microbial in nature. Micro-organisms and the communities that they form can be complex, but I do not think that macro-organisms or intelligent life evolved in the Solar System. Micro-organisms can harbour and manipulate small niches on planets. Larger organisms need a larger environment for support. Most environments we have observed beyond Earth do not seem conducive to supporting the physics and chemistry of macro-life forms.

## What future astrobiological missions could be of most interest?

Of all the places for us to explore for possible past or present extraterrestrial life, Mars offers our best opportunity to find it. It's close and the environments are similar enough to Earth's that we can figure out how to best explore them. Exploring extremely unfamiliar environments is equally important to astrobiology. Venus, Titan, Europa and other bodies in the Solar System have conditions that are so different from Earth's that they challenge us to think outside of the box, which will also provide us with an observational baseline for exoplanet comparison.

## Which do you think will be first to find signs of extraterrestrial life: robotic exploration, planet hunting or signal detection (SETI)?

I think robotic exploration poses our best chance of observing signs of extraterrestrial life since most life beyond Earth is probably microbial, if it exists.



## BIO

### Dr Jennifer Eigenbrode

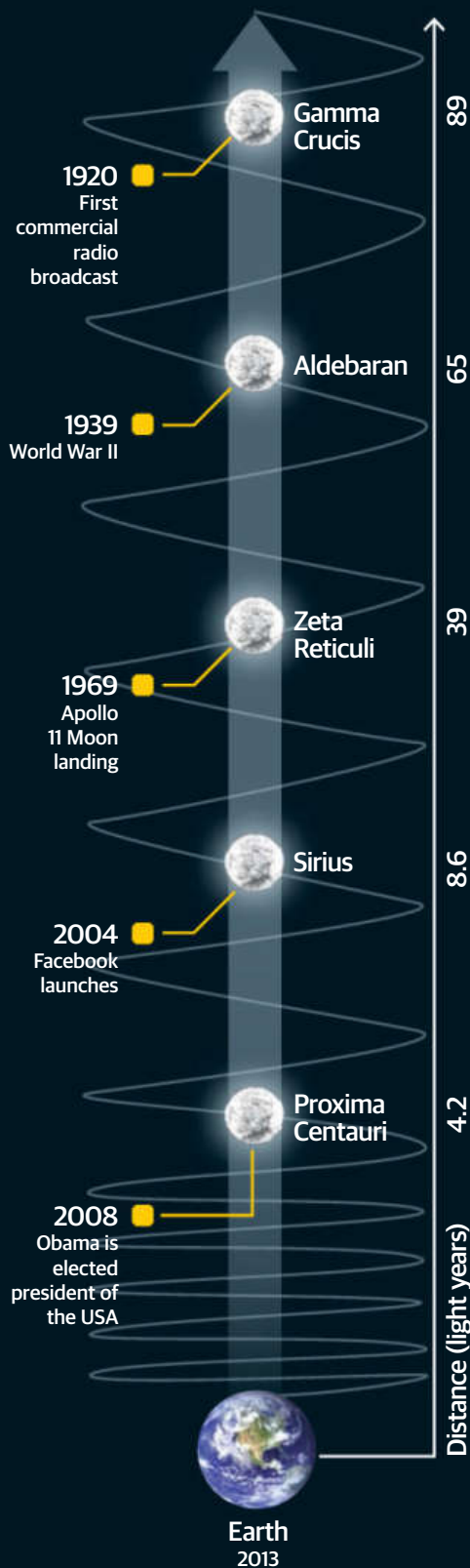
Dr Eigenbrode is a research scientist at NASA Goddard Space Flight Center, who specialises in astrobiology. She is also a participating scientist on the Mars Science Laboratory mission.

**"Robotic exploration poses our best chance of observing signs of extraterrestrial life"**



# Interstellar broadcasts

For the past 100 years we've been broadcasting our position to the rest of the galaxy, but how far have our signals actually reached?



## Search for life

**Is anyone out there?**  
We've been sending out signals for just 100 years, so only life within a circle 200 light years in diameter around Earth would hear us

their atmosphere, a vital clue in discerning whether they are habitable or not. Groundbreaking research into the possibility of measuring the atmospheres of exoplanets for signs of methane, oxygen and other elements, or even looking for signs of artificial lights (just as we can see the Earth at night from space) will bring us closer to finding alien civilisations.

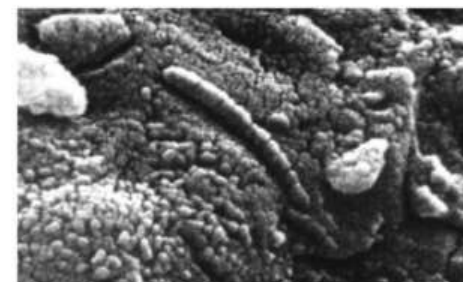
While we're searching for alien life, however, could it be possible that other extraterrestrial races are also doing the same thing? We've been broadcasting our position, both intentionally and unintentionally, by emitting radio waves for about a century. If anyone is within 100 light years of Earth, they will be able to hear us. In fact, in 1974 we sent out something called the Arecibo message, a broadcast of radio waves that, for the first time, contained data about humanity that could be interpreted by an alien race and understood to be a call from our civilisation to theirs. It's not inconceivable to think that other races might have done the same thing; maybe there are thousands of Arecibo messages streaming through the galaxy, but we just haven't come across one yet.

With all this talk of exoplanets, habitable worlds and aliens, however, you might be forgiven for having one question burning in your mind; if there really is intelligent life out there, then where is everyone? You're not alone in thinking this. Way back in 1950, astrophysicist Enrico Fermi asked this very question, which became known as the Fermi paradox. He argued that because the galaxy isn't teeming with spacecraft, or that we've never been sent a message from aliens, then either interstellar travel must be impossible (therefore dashing our hopes of ever exploring the galaxy) or we are the only intelligent civilisation in the universe.

There are a number of explanations as to why this is so, but the most plausible relates to the history of a planet like Earth. Our planet is 4.6 billion years old, but only in the last several hundred million years has it been inhabited by sophisticated organisms. Only in the last several thousand years has intelligent and sentient life, namely humans, made its mark on the globe. And only in the past one hundred years have we seriously begun observing and exploring the cosmos, and also sending out signals of our own. Humanity won't be around forever; an extinction event, either natural or man-made, could cut short

## Have we already found life?

There have been several instances where controversial evidence suggested that we may have already found life elsewhere in the universe



### Allan Hills 84001

In Antarctica on 27 December 1984, a team of American scientists found a meteorite named Allan Hills 84001 (ALH 84001) that shot to fame 12 years later when it was announced that it might contain microscopic fossils of Martian bacteria. However, no conclusive evidence could prove whether this was so.



### The Viking probes

In 1976, NASA landed two probes on Mars, Viking 1 and 2, which had instruments to perform biological experiments on the surface. Controversy surrounded the results; early indications suggested they'd found evidence of organic compounds, but some claimed that the nature of the experiment, which heated soil samples, would have destroyed organics, suggesting the results were erroneous.



# Translating an alien language

**Dr John Elliott**

## What work do you do for SETI?

My contributions in the academic side are in being able to understand the structures in the signal if we receive one. There's been at least one occasion where I've looked at a signal, just to see if there's any structure in there. So if they pick something up, I'll be looking at the content to see if there's anything in there that denotes intelligence, any sort of linguistic phenomena or imagery or anything with structure that's actually conveying information.

## How confident are you that you could decipher the message?

It obviously all depends on the amount of content you've got. If it was just a short burst, like the Wow! signal, then you're up against it. But if it was someone on the other end broadcasting an encyclopedia, then you've got a great chance of deciphering it. And if there's a crib [key] attached to it then you've got some way to unlock it or decipher it. If it's something very simple but with enough information then you could start to pick it apart and be able to have a good guess at what they are saying like "hello", "we are here", this sort of thing.

## Would you respond to their message?

The flip side of all this is message construction. Because of the nature of the deciphering side I'm sort of one of the main people that deals with the message

construction because one is relevant to the other.

Constructing a message is a big debate for SETI, it splits us down the centre. Should we send a message back? Many of us, me included, are in the camp that, yes, for God's sake, they're going to be huge distances away from us, let's just try to communicate!

## What would we say to them?

The obvious thing is to copy what they've sent back to them with something of our own included. There are some people that send messages [without consent] anyway. People are sending messages purposefully out from Earth, and that's an issue. While we are debating whether to send a message, some people are already sending them. You'll end up in the hands of amateurs there if you don't watch it.

## Will we ever find a signal?

Yes. There's a huge universe, at least ten to the power of 21 stars out there, and there's at least that number of planets. We've only just started searching the sky. Our ability to listen to the universe is exponentially growing. There are so many planets out there in habitable regions that, just through the power of measuring probability, life has got to be out there. I can't think of a sensible argument that would say it isn't. I wouldn't mind putting money on it, although I might not be around by the time they find it! But I think they will.

## BIO

### Dr John Elliott

Dr Elliott is a Reader in Intelligence Engineering at Leeds Metropolitan University in the UK. He has been involved with SETI since 1999, and his research includes the post detection decipherment of an extraterrestrial signal.

**"I'll be looking at the content to see if there's anything in there that denotes intelligence"**



## Get involved with SETI

If you're interested in becoming an alien hunter, then there's never been a better time to get involved with the SETI Institute. Head over to the website at [www.seti.org](http://www.seti.org) to find out more.

You can also sign up for SETI@Home, a piece of software that runs in the background on your computer and makes use of processing power that is otherwise unused.

our ambitions to continue exploring. That would mean that an intelligent civilisation has only a brief period to make a mark in the lifetime of their planet. If we're going to find one, we're going to need to continue our extensive search, as it may be that every habitable planet has only a comparatively brief window in which intelligent life thrives.

However, searching for intelligent extraterrestrial life isn't the only hunt currently on the go. As mentioned earlier, our robotic exploration of the Solar System is looking at the possibility of microbial life residing on the surface of Mars, or perhaps one of the potentially habitable moons such as Europa, Ganymede or Titan. From landers to orbiters to probes, we've barely scratched the surface of the secrets some of the other destinations in our Solar System might be hiding.

In the mid-Seventies, NASA conducted the first astrobiology experiment outside of Earth, sending its Viking 1 and 2 landers to Mars to dig into the soil and look for signs of past or present life on the Red Planet. The results proved to be inconclusive but they sparked a hunger to learn more; right now, the Curiosity rover is making its way across the

Martian surface to answer the very same question. And even here on Earth, research is proving useful. We've found life in the deepest, darkest and coldest places, whether it's at the bottom of a frozen lake or in highly acidic environments. Research like this could help us to one day look for life on frozen worlds like Europa or liquid-bearing places like Titan. In this regard, astrobiologists are hopeful of one day discovering microbial life.

Therefore, in our continued hunt to prove that Earth is just one world where life has made a mark in the universe, it will be down to the work of various people around the globe to make the vital discoveries that could indicate the presence of intelligent or basic life elsewhere. Whether it's experts at NASA working on a high-profile, next-generation planet-hunting machine such as the James Webb Space Telescope, or it's the valiant workers who are looking for signals outside of our Solar System at SETI, or even the astrobiologists searching for bacteria on another world, these dedicated people will continue to work towards finding alien life. They are convinced we are not alone in this universe and they aim to prove it, one way or another. ■



# 5 amazing facts about Rockets



## The first rocket landed in a cabbage patch

The first-ever liquid-fuelled rocket was launched by American Robert Goddard on 16 March 1926, although the Chinese used solid-fuel rockets a thousand years prior. Goddard's rocket climbed 12.5m (41ft) before crashing in a cabbage patch. However, he was widely derided for suggesting a rocket could one day take humans to the Moon.

## The Saturn V was heavier than 400 elephants

Coming in at a massive 2.8 million kg (6.2 million lb), the Saturn V is the most powerful rocket to have ever been launched. It was as tall as a 36-storey building and could take the equivalent of ten school buses into Earth orbit, while the amount of fuel it used could have driven a car around the world 800 times.

## Paint designs keep track of rockets

Many rockets use different paint styles so ground controllers can track their motion, roll and orientation. The iconic Saturn V used chequered paint for this purpose, as did the early Redstone and Titan rockets. Modern rockets use the External Vehicle Markings (EVM) Document, which outlines a function for each paint marking.

## The fastest rocket ever approached Mach 50

The quickest rocket to ever be launched was a five-booster configuration Atlas V on 19 January 2006. It carried the New Horizons spacecraft, which is currently on its way to Pluto, and reached over 58,000km/h (36,000mph). At this speed it got to the Moon's orbit in just nine hours, compared to the three-day journey time for Apollo astronauts.

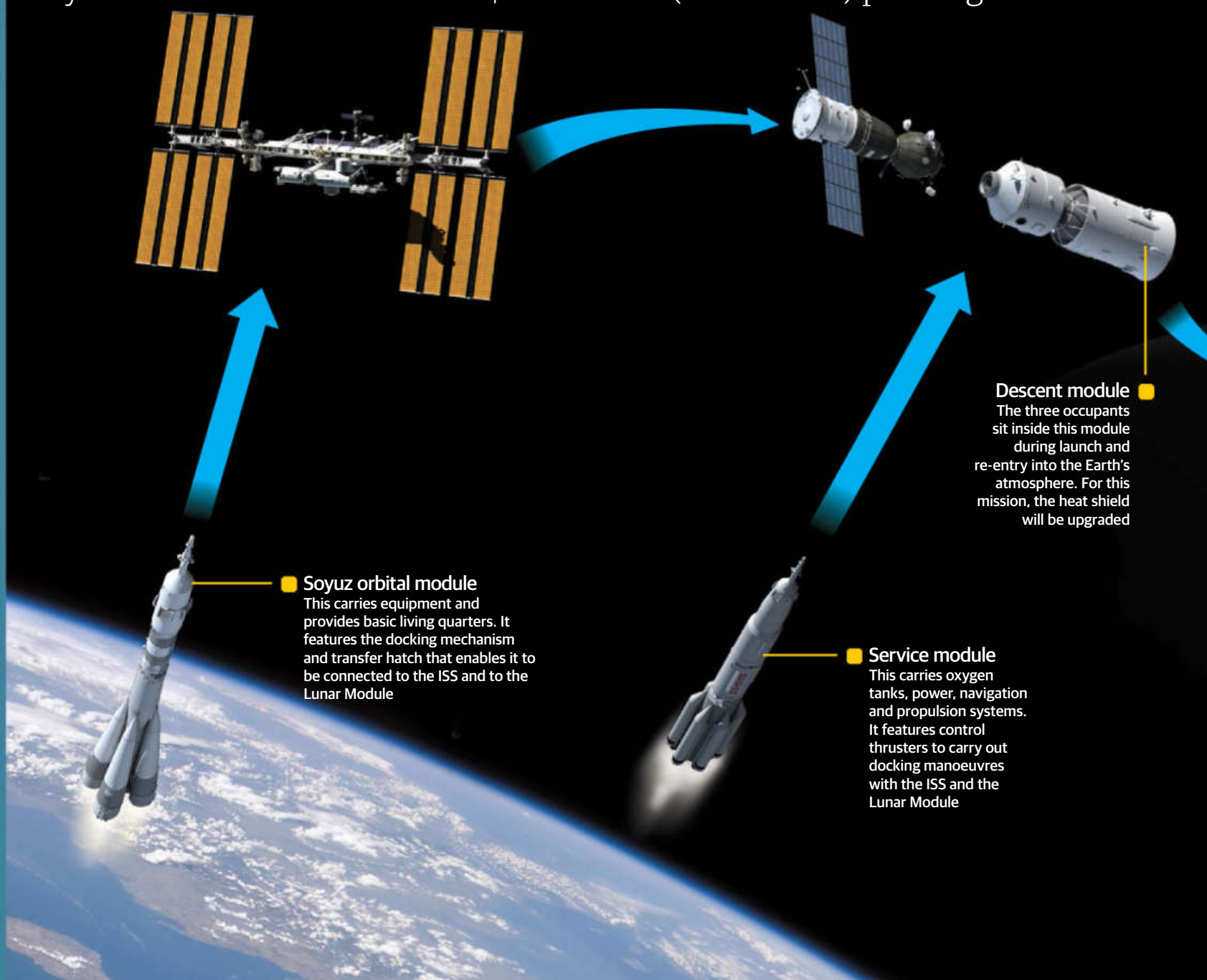
## Russia has launched the most rockets

As of December 2011, 50.5% of all spacecraft launches (3,595) were carried out by Russia. Of the 7,120 spacecraft launched, the USA is responsible for 1,857 (26.1%), while Europe's count is at 338 (4.8%). Since the dawn of the space age in 1957 the busiest year for rockets so far was 1965, when 180 spacecraft were launched.



# Millionaire Moon tourism

Fancy a trip around the Moon? That's what Space Adventures is offering to anyone who is able to afford the \$150 million (£90 million) price tag





## Destination Moon

It will take a few days to reach the Moon from the ISS. The spacecraft will swing around the normally hidden far-side and offer a view of Earth rising above the Moon. The last time this was witnessed was in 1972 by the crew of Apollo 17, the final mission of the Apollo program

## Habitation module

The two tourists and professional cosmonaut will transfer from the Soyuz spacecraft to live in here during their journey to and from the Moon

## Propulsion

This uses the Block DM space tug that has been regularly used as an upper stage on the Proton rocket to launch satellites into Earth orbit. It fires the two docked craft towards the Moon

been successfully used with the Proton rocket to send unmanned craft to the Moon, Mars and Venus.

The Soyuz itself consists of three modules; a spherical living module at the front, an aerodynamically shaped re-entry module and a service module that carries the main engine, fuel tanks and solar panels. Only the re-entry module will return to Earth.

Once the Lunar Module is safely in orbit, the tourists, along with a professional Russian cosmonaut, will re-enter the Soyuz spacecraft. They will then leave the trusty ISS to rendezvous and dock with the Lunar Module. The module will provide far better and bigger living quarters than the Soyuz, and the Block DM engine will send the two docked craft in a trajectory around the Moon and back to Earth. The circumlunar flight will take them within 100 kilometres (62 miles) of the lunar surface and they will enjoy the sight of the normally hidden far-side of the Moon. Not only that, they will also get a spectacular view of planet Earth rising above the surface of the Moon. This part of their space vacation will last six days and culminate with it jettisoning the Lunar Module and returning to Earth inside the Soyuz spacecraft. The Soyuz capsule communications and navigation systems will be upgraded, and it will need a different heat shield, as the craft will re-enter the Earth's atmosphere at a greater speed than if it was merely returning from Earth orbit. By skipping the Soyuz through the atmosphere, it will slow enough for it to make a parachute landing to the ground. If there is sufficient demand, Energia and Space Adventures will launch a series of expeditions to the Moon. ■

Multi-million and billionaires can book their flight around the Moon for as early as 2018, using Space Adventures' imaginative use of existing spacecraft and technology. An essential cornerstone of this project are the Soyuz rockets, spacecraft that were originally designed to take cosmonauts to the Moon. They didn't achieve that goal, but in the Sixties and Seventies they were easily adapted to ferry cosmonauts and astronauts into Earth orbit and to space stations. In the decades since the demise of the Space Shuttle, the Soyuz craft has become the world's safest and most cost-effective spacecraft.

Each trip to the Moon will carry two tourists, who will spend at least eight months preparing themselves for the high G-forces of lift-off and the weightlessness of space, along with training in operating the Soyuz module, collecting data and conducting experiments. They will blast off from the Baikonur Cosmodrome in Kazakhstan, and

dock with the ISS, where they will stay for ten days. While there, they will become acclimatised to living in space, carrying out a few observations and experiments. Meanwhile, a Proton rocket will blast off from Earth to deliver a Lunar Module into low Earth orbit. This unmanned craft will consist of a living module and a Block DM propulsion stage.

The Proton rocket and Block DM are other blasts from the Soviet past. The Proton rocket was originally designed as an intercontinental ballistic missile, but the plans changed in the hope that it could be used to send cosmonauts around the Moon before the Apollo program. Since then it has been regularly used to launch satellites into Earth orbit.

The Block DM was developed as the upper stage for rockets taking unmanned craft to the Moon. The 5.5-metre (18-foot)-long, four-metre (13-foot)-diameter space tug has a main engine that can be fired several times over a multi-day mission. It has



# INTERSTELLAR SPACE TRAVEL

The science behind the  
warp drives that could  
take us to the stars







## Interstellar space travel

going to explore beyond our own Solar System so long as we continue travelling at the speed of our current probes. Even at the speed of light, the universe is still far too massive for us to comfortably explore. It would take more than 100,000 years to cross our galaxy, 2.5 million years to reach the next one, and 45 billion years to reach the edge of the known universe. What we need is some way to travel faster than the speed of light. The problem is that Einstein said this is impossible.

Here's the reason: Einstein's law of special relativity says that the speed of light (referred to by the letter 'c') is always constant, no matter where you are in the universe or how fast you are moving. If you shine a torch out of the front window of a spaceship that is travelling at half the speed of light (0.5c), that beam travels away from you at 1c. An observer, however, hovering in space as you zoom past would also see the beam travelling forward at the speed of light, not 1.5c as you might expect. And if you shine it out of the rear window, both of you will still see the beam travelling at 1c. This is because relative velocities don't just add together in a simple way. It only seems that way to us on Earth because it's an approximation that works at low speeds. The faster you go, the less accurate this approximation is, but the difference is only really appreciable once you go faster than about ten per cent of the speed of light (0.1c).

As a rocket fires its thrusters, it gets faster, but the amount its speed increases by for each second of thrust is less each time. The rocket could accelerate forever and still never reach the speed of light. This is why physicists say that it would take infinite energy to reach the speed of light - infinity is another way of saying 'never'. If you can't reach the speed of light, it follows that you can't ever go faster than it. This is true for any object that has mass.

Suppose we give up on exploring the universe, or even the galaxy. What if we simply settle for just travelling close to the speed of light without actually exceeding it? There are at least 50 stars within 16 light years of Earth, which would let us send a probe there and beam back the data in the same amount of time that the Voyager missions have been running. If you accelerate your probe at a constant 1G (a unit of acceleration that roughly equals ten metres [33 feet] per second squared) for two years, it would be travelling at 97 per cent of the speed of light by the end. That certainly sounds manageable, until you consider the logistics of firing an engine for that long. The Saturn V rocket used for the Apollo missions, for example, fired its engines for less than 20 minutes total at an average acceleration of about 1.5G. In order to achieve even this short period of acceleration, the weight of the discarded stages and fuel was 60 times the weight of the spacecraft that it propelled to the Moon.

To accelerate a rocket continuously for two years, it would need a lot more fuel, but that fuel would need to be accelerated as well, which would require even more fuel and so on. This runaway cycle gets out of hand very quickly indeed. In fact, even if you only wanted to accelerate your space probe to about 0.5 per cent of the speed of light, so that it could

To date, mankind has managed to send just one object beyond the boundary of our own Solar System. Voyager 1 received gravity assists from both Jupiter and Saturn that boosted its speed to over 61,000 kilometres (38,000 miles) per hour, but it still took 35 years to spiral outwards into interstellar space, 20 billion kilometres (12 billion miles) away. At this speed, Voyager 1 would take another 75,000 years to reach our nearest star, Proxima Centauri.

That's because 61,000 kilometres (38,000 miles) per hour is actually very slow. It's just 0.005 per cent of the ultimate speed limit for the universe: the speed of light. If you drove your car at the same fraction of the motorway speed limit, you would be travelling ten times slower than a snail. Clearly, we are never



### The father of the warp drive



Dr Miguel Alcubierre tells us about his 1994 paper that covered warp drives and bubbles in space-time

#### Does general relativity permit warp bubbles for warp-drive technology?

Warp bubbles are theoretically possible in the sense that the required geometry of space-time is easy to write down. However, they are certainly not solutions in a strict sense.

#### What are the biggest obstacles to creating one?

1: The warp drive would require 'exotic matter', with negative-energy densities (antigravity) that - as far as we know - do not exist. It would also require some very weird distributions of momentum and stresses. 2: Even if you get your hands on negative energy and manage to manipulate it, you would need star-sized amounts of it. 3: At super-luminal speeds, the front of the warp bubble is disconnected from the centre. This means that a spaceship sitting in the centre of the bubble has no way of placing the required matter and energy at the front of the bubble. As a super-luminal warp bubble cannot be created from within, it would have to be set up in advance from the outside.

#### What happens to the ship if the warp bubble collides with an object while in motion?

It depends on the details of the geometry. Of course, hitting anything at a high speed is always very dangerous.

#### Are there other risks with manipulating space-time directly?

These are questions that can't be answered without knowledge of the properties of the negative energy, which might not even exist. It's like asking the Ancient Greek philosopher Democritus if you could use his atomic theory to build a bomb.



The Helix Nebula is one of the closest to Earth, but even travelling at light speed, it would take a craft 700 years to reach it. There has to be another way

reach Proxima Centauri in 850 years, a chemical rocket would need more hydrogen fuel than there is in the entire universe!

You could improve efficiency by switching to nuclear rockets that use fission or fusion to propel your ship with superheated streams of gas. Or, for the ultimate efficiency, you could use matter-antimatter conversion. This might drop the total amount of propellant you'd need to about ten railway tankers' full. Yet if you want the probe to slow down at the other end, you'd need to bring ten railway tankers' worth of propellant to your destination, which would increase the amount of propellant you'd need to get it there to about a thousand supertanker ships' worth of antimatter; a substance that is incredibly difficult to produce. It would take scientists at CERN an entire year to create just a billionth of a gram! Not the most efficient production line.

It's possible that in the future we may be able to do away with the need to carry propellant on the spaceship at all. In August 2014, a research team at NASA tested a device that appears to produce thrust out of nowhere by bouncing microwave beams inside a closed chamber. If - and it's a big if - the results aren't due to experimental error, this device, known as the Cannae drive would appear to break a fundamental law of physics. A less speculative, propellantless propulsion system would be to use a light sail that catches a stream of photons fired from a highly-focused laser on Earth. Whichever way you do it, you still have to deliver enough kinetic energy to the spacecraft to increase its speed and even without the effort of accelerating the mass of the propellant, the energy requirement is enormous. NASA's Glenn Research Center has estimated that sending something the size of the Space Shuttle on a

## Journey to Proxima Centauri



**World land speed record:**  
0.34km/s (0.2mi/s)  
**Journey time:**  
3.7 million years



**SR-71 Blackbird:**  
0.98km/s (0.6mi/s)  
**Journey time:**  
1.3 million years



**Voyager 1:**  
17km/s (10.6mi/s)  
**Journey time:**  
75,000 years



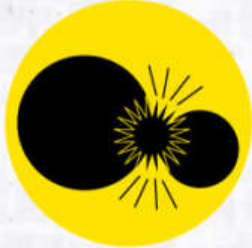
# The dangers of warp travel

Even if we manage to build a warp drive, would we dare turn it on?



## RADIATION

Researchers at the University of Sydney in Australia have calculated that particles and radiation could be caught up in the bow wave of a warp bubble as it travels. When the ship decelerates, the accumulated particles would be released in a devastating burst that would destroy anything in the path of the ship.



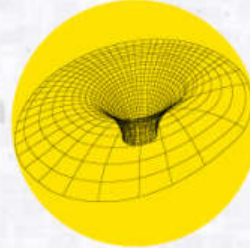
## COLLISIONS

The physics of warp bubbles aren't well enough understood yet to know exactly what would happen if your course takes you through the path of a planet or star. Would it be brushed aside? Would you pass harmlessly through it? Or would you be instantly vaporised? If you fly inside the event horizon of a black hole, could you escape?



## NEGATIVE ENERGY

What are the properties of negative energy? How would you store it? What happens if your negative-energy battery short-circuits? Whatever the details of the ensuing catastrophe, the numbers involved are likely to be so big that it could destroy the Solar System, never mind the spaceship.



## BLACK HOLES

Even if the negative energy doesn't explode, distorting space-time so heavily could easily create a singularity, where space-time curves in on itself completely – in other words a black hole. Even if the spaceship itself escapes inside its own warp bubble, the consequences for those left behind would be disastrous.



## VIOLATING CAUSALITY

In certain circumstances, travelling faster than the speed of light can enable you to travel back in time. If the universe doesn't somehow prevent this, you could create all sorts of mind-bending paradoxes, such as going back and killing the inventor of the warp drive, or your very own grandparents.

“It's possible that in the future we may be able to do away with the need to carry propellant on the spaceship at all”

50-year one-way trip to our nearest star would need 70 million trillion Joules of energy. This is equivalent to diverting the entire electricity-generating capacity of the UK full-time for all of those 50 years. However you do the sums, conventional propulsion techniques just aren't powerful enough to explore the stars.

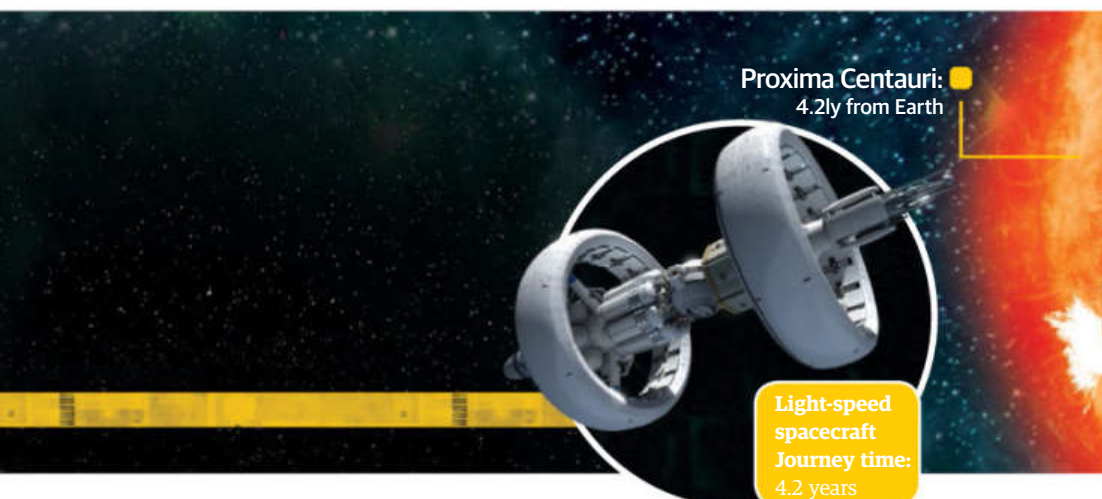
Yet there might be a loophole. Special relativity says that no object can be accelerated to the speed of light, but it doesn't say anything about how fast space itself can move. Think of an airport travelator. You walk along it at your normal pace, but because the

floor is moving as well, your total speed seems much faster to someone walking beside the traveler. We aren't adding the velocities of two objects moving on the ground; instead we are moving the very ground we walk on. Einstein's theory of general relativity showed that the three dimensions of space itself can be stretched and curved. It's a bit like a map. Maps can be flat and show places according to their positions along the width and length of the paper, or they can be globes that show them using latitude and longitude. The map is two-dimensional in both

cases, but with a globe, those dimensions are curved into a third dimension. Over short distances, if the curvature is quite small, the surface of the globe will still seem flat. But if you stretch it more dramatically, some interesting things happen.

Suppose our universe globe is painted on a balloon and you push your fingers in from opposite sides so that the surface gets more and more indented. Eventually, your fingers are touching, with just the skin of the balloon between them. If you could punch through this skin without bursting the balloon, you could hop from one side of the universe to the other without travelling all the way around the outside. This form of distortion is called a wormhole.

One common objection that is raised against wormholes as a practical form of travel is that you need to position the far end where you want to go before you can travel there. If the ends of the wormhole are some kind of Stargate device, you would need to physically transport one of them there at sub-light speeds first. However, the amazing properties of wormholes could come to your rescue. A spacecraft carrying a Stargate doesn't need to bring its own fuel because you can just pipe fuel through the wormhole and have it delivered instantly, regardless of how far the ship has travelled. This doesn't violate the law of conservation of energy, because the extra mass you have supplied to the travelling ship causes the wormhole to shrink. To keep the size of the wormhole constant, you would need to pump extra energy into the device that powers it. According to professor John Cramer of the University of Washington, every kilogram (2.2 pounds) of fuel that you send through the wormhole would need 25 million megawatt-hours of extra power to keep the wormhole open. This is roughly as





# Warp drive starship

Dr Harold White's warp travel spacecraft of the far future

### Solar panels

When the ship isn't travelling at warp speed, it will still use old-fashioned solar power in order to preserve its precious supply of antimatter fuel for the warp drive

### Impulse drive

There may be restrictions on using warp drive at low speeds or when near planets, so traditional reaction jets will still be needed when it comes to manoeuvring

### Warp rings

The energy needed to create the warp bubble is greater if the boundary of the bubble is sharp. Using thicker rings, Dr White thinks we could produce a thicker warp field

### Crew section

In the middle of the warp bubble, space-time is perfectly flat, so the crew will experience absolutely no acceleration as they make their way between the stars

### Communication array

The warp bubble is disconnected from the rest of the universe, so the crew will only be able to communicate with Earth when the warp drive is turned off

### Fuel tanks

A warp drive may need antimatter to supply enough energy. This will have to be stored inside electromagnetic-confinement tanks to stop it from touching the sides of the ship

### Space efficient

The larger the warp bubble, the more energy it will inevitably need, so it is important to utilise the space inside it as efficiently as possible to store as much energy as it can

...the world produces every five weeks, so even if we diverted all of our combined power into the Stargate, we would not be able to send more than two kilograms (4.4 pounds) of precious fuel every month.

Imagine we have access to enough electricity to be able to pump fuel constantly through the wormhole and allow the spaceship to accelerate close to the speed of light (let's say 99.995 per cent) and we send it to Tau Ceti, a star 12 light years away. You might assume that it would be about 12 years before the spaceship would arrive and we could use our wormhole, but Einstein showed that time slows down the faster you travel.

At 99.995 per cent of the speed of light, time would pass 100 times more slowly. So for the captain of the ship, the 12-year journey would only appear to have taken 44 days. This is only true for time aboard the spaceship of course, but remember that the Stargate it carries is connected through the wormhole to the other end on Earth. Anyone looking through the wormhole would see the same view out of the front window of the spaceship as the captain sees. This means that after just 44 days they would see Tau Ceti loom into view, while Earthbound telescopes would see that the spaceship was only one per cent of the way there!

Convenient as this sounds, it raises a much bigger problem with faster-than-light travel. Ian Crawford is professor of Planetary Science and Astrobiology at Birkbeck, University of London. "With a faster-than-light drive, you can contrive situations where you would go backwards in time," he says. "And that is a big problem. If it's possible to travel faster than light then there must be some higher-order physical law that would prevent you from messing around with causality." Theoretical physicist Stephen Hawking calls this the chronology protection conjecture. "When space-time gets warped almost enough to allow travel into the past," he says, "virtual particles



### International co-operation

The resources needed to research, develop and build a warp ship will exceed the budget of any one country, so every nation will need to join in

[becomes] very large. This means that the probability of these [alternative] histories is very low [...] making the world safe for historians."

So wormholes might stretch space-time to breaking point, but there are other ways to warp it that might allow us to travel faster than light, without travelling into the past. In 1994, Mexican physicist Miguel Alcubierre published a solution for the equations of general relativity that showed a way to create a bubble of distorted space-time around an object. By contracting space-time in front of a spaceship and expanding it behind, you could create a ripple in space-time that could roll across the universe, carrying the ship with it. The patch of space-time immediately surrounding the ship would be flat so the ship wouldn't actually be moving in the traditional sense, but it would be carried on the ripple of curved space-time, like a surfer riding a wave.

We don't know how to make wormholes or warp bubbles yet. All we know is that general relativity doesn't forbid them. However, the distortions that you need to travel faster than light involve bending space-time in the opposite direction to the way that gravity bends it. That suggests we would need negative matter or energy to achieve it. As exotic as that sounds, it's possible that negative energy may actually exist. If you put two metal plates in a vacuum chamber and hold them about ten nanometres apart, they will be pulled together by something called the Casimir effect. This is thought to be because even a total vacuum has some energy and the space between the plates is too small for all the possible wavelengths of this vacuum energy to fit in it. So the gap between the plates somehow has less energy than the ordinary vacuum and they are pushed together by vacuum energy on the outside surfaces. Seeing as the energy of the vacuum is zero, by definition, this means there is *negative* energy between the plates.

Miguel Alcubierre dismisses this form of negative energy. "Even if it exists, we have absolutely no idea how to use it for anything useful, let alone a warp drive." Professor Crawford raises an even more fundamental objection. "The Casimir effect arises out of the quantum vacuum [...] We're trying to use quantum theory to generate negative energy as a way of keeping wormholes open, which are a prediction of general relativity, and we know that we can't marry quantum theory to general relativity yet." In the same way that the theories of electricity and magnetism were eventually realised to be different aspects of the same thing (electromagnetism), theoretical physicists have been working for decades to produce a theory of quantum gravity. "When we do have a theory that reconciles general relativity and quantum theory, we don't know whether these loopholes will still be there," warns Crawford. "They might disappear once we have a more complete theory of gravity. On the other hand, a more complete theory may tell us that it's easier than we thought."

There are an estimated 10,000 times more stars in the night sky than there are grains of sand on Earth. If one per cent of them have Earth-like planets around them and one per cent of those have life and one per cent of *those* have intelligent civilisations, that's still about 10 million billion civilisations in

the observable universe. If warp travel is possible, it seems even more extraordinary that we haven't been visited by any of them yet. This is known as the Fermi paradox, after physicist Enrico Fermi. One possible solution, known as the Zoo hypothesis, is that some sort of Prime Directive exists whereby spacefaring aliens all agree not to interfere with less advanced species. "The problem with the Zoo hypothesis," says Crawford, "is that it would require all of these aliens to agree to the same set of rules for the zoo."

According to Crawford, the only way this might be plausible is if warp travel is possible. "In the context of near-instantaneous travel and communication, then it becomes possible to imagine galactic political structures - Empires and Federations - that might be able to impose quarantines on planets where intelligence has just emerged. Yet it also makes it much easier to travel interstellar distances, so in fact there is a balance between galactic-scale political institutions that can force Prime Directives and the fact that there will be many more intelligent beings flying around the galaxy."

NASA's official stance on warp travel places it firmly in the realm of speculation. This doesn't mean they are ignoring it completely though. Dr Harold White at NASA's Johnson Space Center in Houston, Texas, is working on a modified version of a device called a Michelson interferometer, which will use a ring of high-voltage capacitors to induce a small warp field. If it works, it should be possible to detect it by shining a laser through the field and measuring its speed. Results so far have been inconclusive, but professor Crawford applauds the effort. "Because the physics is still just not understood, most professional physicists won't engage with it. It's just considered too speculative. So it's hats off to people like Alcubierre and Harold White and others who are sticking their heads above the parapet and pursuing the research seriously. I do think that's worth encouraging."

Ultimately, even if warp drives are possible, professor Crawford believes there's no guarantee that they would be any easier to build or less expensive to power than sub-light spaceships. "We don't know what's involved in building a faster-than-light probe, but we know we aren't going to wake up one morning and find that we've got it for Christmas. It's going to have to be developed, and developed from physical principles we don't understand. Interstellar space travel is really a matter of learning to walk before you can run. We have to gradually build up an industrial infrastructure within our own back yard, moving out into the Solar System, where eventually we will develop the expertise and the economic wealth that will enable us to invest some fraction of that in interstellar exploration."

Warp-drive research might seem like the philosophers' stone of space engineering, the substance that could turn other metals into gold. The quest for this shortcut to riches was one that obsessed alchemists for centuries and, of course, they never found it. However, their search laid the foundations for the understanding of chemistry that we have today, which eventually gave us electricity, nuclear power and rocket fuel. So perhaps it wasn't entirely a waste of effort after all. ■

"With a faster-than-light drive, you can contrive situations where you would go backwards in time" **Ian Crawford**



# Warp-drive tourism

Unless warp drive turns out to give us infinite speed, journeys beyond our galaxy are probably still out of reach. If we could travel at 1,000 times the speed of light, however, some very interesting places in the Milky Way would suddenly become accessible for us.

**ly = Light years**

## M80

**Distance: 32,600ly**

On the furthest side of the Milky Way to Earth, this globular star cluster is packed with hot blue straggler stars, which seem out of place and might have been captured by M80's gravity from another part of the galaxy

## Arches cluster

**Distance: 25,000ly**

This is the most densely packed group of stars in the galaxy. This cluster is only about two million years old and contains some mysterious magnetic fields that trap arches of high-energy particles

## Blue stragglers

**Distance: 26,000ly**

Blue stragglers are a rare and puzzling sort of star that may form when binary stars merge. This reinvigorates their nuclear fusion, making them seem younger than the other stars in their neighbourhood

## Galactic core

**Distance: 26,000ly**

The central 30,000ly region of the galaxy is a swirling mass of hot, ionised gas and massive stars. Dust clouds obscure our view of it from Earth in the visible wavelengths of light. This image was taken with the Hubble Space Telescope's near-infrared camera



## Kepler-186f

**Distance: 500ly**

Currently one of the best candidates for the most Earth-like planet award, Kepler-186f is just ten per cent larger than Earth, with a rocky surface and a good chance for surface water. Its star is much fainter though; midday on this planet would be just like an hour before sunset on Earth

## Tau Ceti e

**Distance: 12ly**

The existence of this exoplanet hasn't been conclusively proved yet, but it could be one of the nearest Earth-like planets to our own. With a warp drive, we could quite easily send a probe to take photos of its surface conditions to check

## High-velocity gas clouds

**Distance: 14,000ly**

Lying above the plane of the galactic disk, these clouds constantly bring new gas into the galaxy to allow it to keep producing new stars. We still don't know where the clouds come from though, so it would be very useful to be able to visit them

## Ancient white dwarfs

**Distance: 7,200ly**

The M4 globular cluster in the constellation of Scorpius contains some of the oldest stars in the galaxy. These stars are 13 billion years old and formed quite early on in the life of the universe. They are now almost burned out and quite cool and faint

## Proxima Centauri

**Distance: 4.2ly**

As our nearest stellar neighbour, we should certainly visit to see if it has planets. Proxima Centauri is prone to sudden and dramatic flare-ups though, so it probably doesn't have any native life

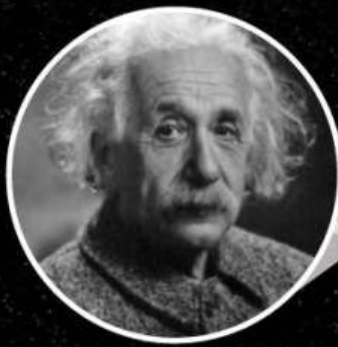
## Sedna

**Distance: 12 Light hours**

The furthest planetoid in our Solar System is puzzling. Its slow rotation suggests it should have a Moon, but Hubble images don't show one. A quick trip with a warp drive could possibly solve the mystery



# The road to interstellar travel



**1916**

**General relativity**  
Einstein shows that space and time form a complex curved shape, which is determined by the amount of energy and matter in it

**1948**

**Casimir effect**  
Dutch physicist Hendrik Casimir predicts that negative energy may create a force between two metal plates. Fifty years later, this force is measured for the first time

1920

1930

1940

1950

**1988**

**Wormholes**  
The possibility of creating a wormhole that you could use to teleport across the universe is suggested by Kip Thorne and Mike Morris

**1994**

**Warp bubbles**  
Mexican physicist Miguel Alcubierre, publishes a paper suggesting that a spaceship could travel faster than light by distorting the fabric of space-time around it

**1969**

First man on the Moon

1970

1980

1990

**2000**

First expedition to the ISS

2000

2010

**2012**

**Voyager 1**  
The first man-made object to leave the Solar System, Voyager 1 is travelling too slowly to cross interstellar distances

**Future**

**Warp Engine**  
We need several major technological advances to happen before Alcubierre's drive could be made a reality





# Discover the Solar System

Exploring the wonders of our Solar System

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Exploding mountains on one of Jupiter's moons

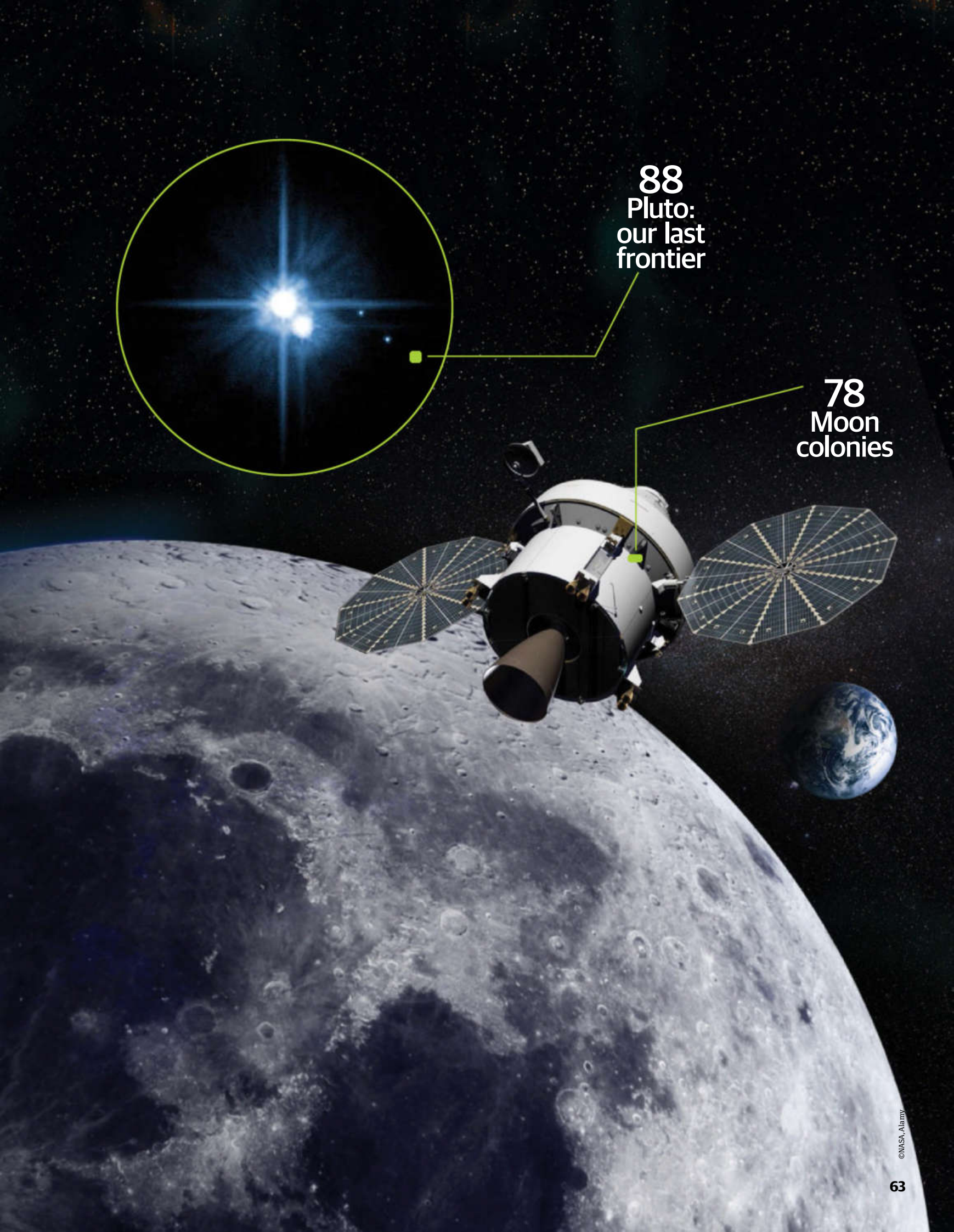
**76**  
The Moon



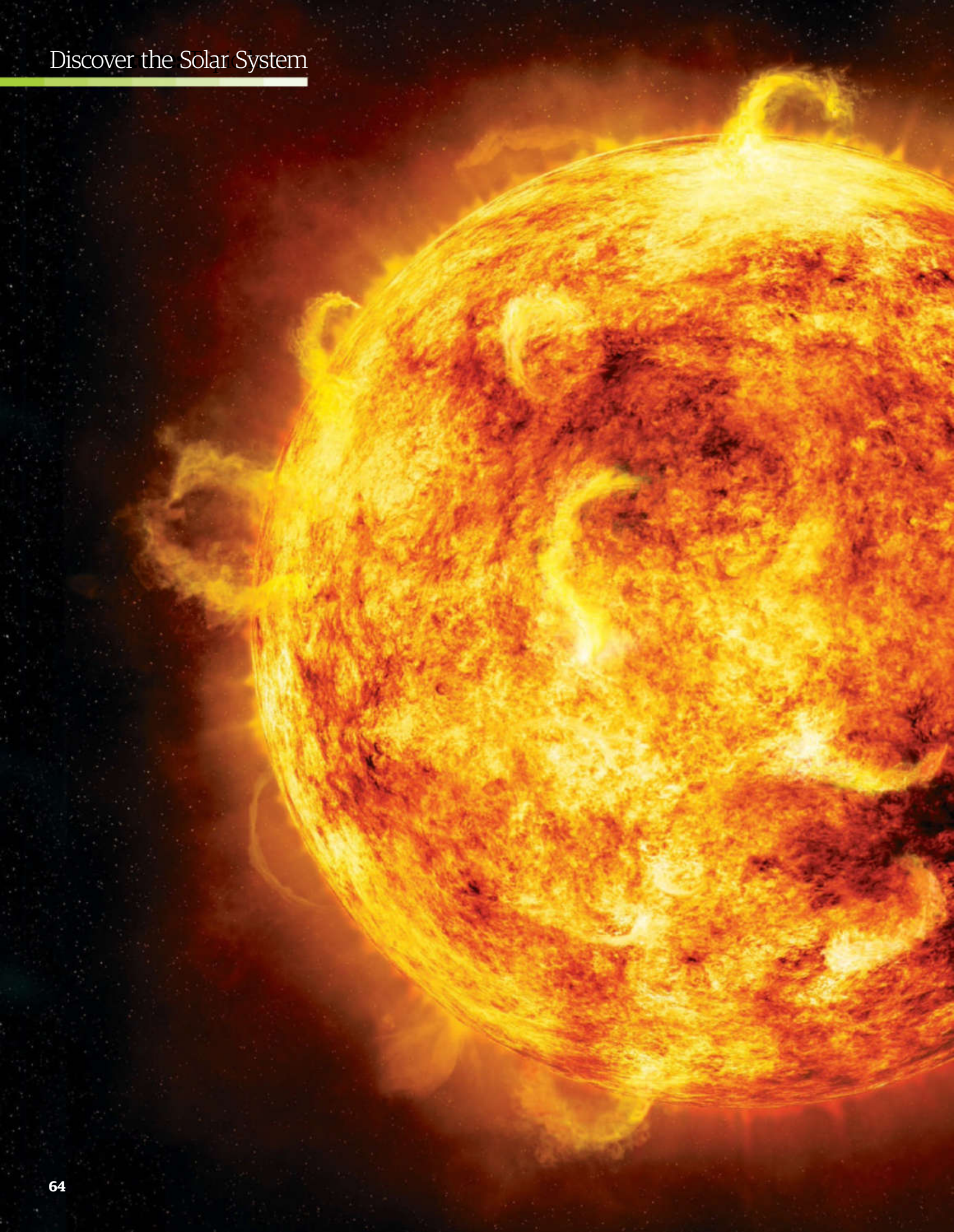


**88**  
Pluto:  
our last  
frontier

**78**  
Moon  
colonies











# All About... THE SUN

The vast nuclear furnace that we know as the Sun is responsible for dictating the seasons, climate and characteristics of every planet in the Solar System. Here, we take an in-depth look at this source of power that has astounded humanity since the dawn of existence



# Discover the Solar System

At about 150 million kilometres (93 million miles) from Earth lies a giant incandescent ball of gas weighing in at almost 2,000 trillion trillion kilograms and emitting power equivalent to 1 million times the annual power consumption of the United States in a single second. Since the dawn of Earth 4.6 billion years ago it has been the one ever-present object in the sky, basking our world and those around us in energy and light and providing the means through which environments, and ultimately life, can flourish. We see it every day and rely on its energy to keep our planet ticking, but what exactly is this giant nuclear reactor at the centre of the Solar System that we call the Sun?

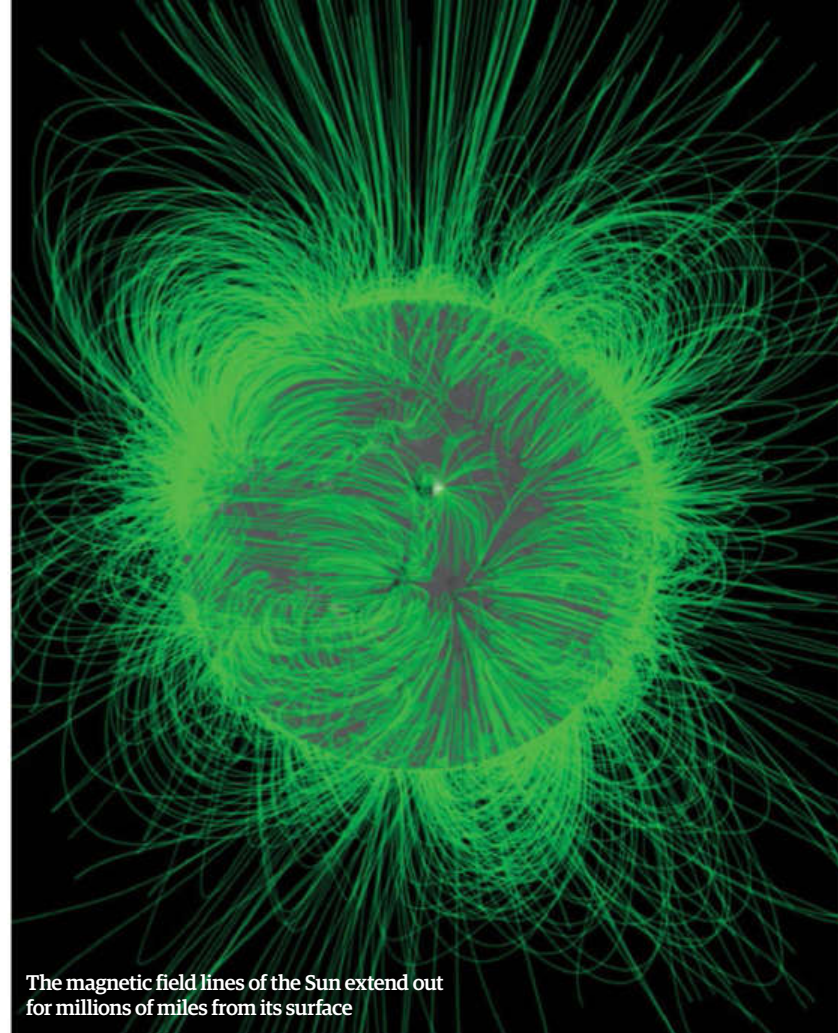
Over 5 billion years ago a vast cloud of dust and gas was located where our Solar System is now. Inside this nebula something huge was happening; gravity was pulling together the debris, likely the remnants of another star going supernova, into one central mass. As the various metals and elements were brought together they began to fuse into an object at the heart of this nebula. This dense clump of matter, called a protostar, grew and grew in size until it reached a critical temperature due to friction, about 1 million degrees Celsius (1.8 million degrees Fahrenheit). At this point nuclear fusion kicked in and our Sun was born.

At the heart of the Sun, hydrogen atoms fused together to produce helium, releasing photons of light in the process that extended throughout the Solar System. Eventually the hydrogen and helium atoms began to fuse and form heavier elements such as carbon and oxygen, which in turn formed key components of the Solar System, including humans. To us, it's the most important object in the sky. An observer watching from afar, however, would see no discerning qualities of our star that would make it stand out from any of the other

hundreds of billions of stars in the Milky Way. In the grand scheme of things it's a fairly typical star that pales in comparison to the size of others. For instance Sirius, the brightest star in the night sky, is twice as massive as the Sun and 25 times more luminous while Arcturus, the fourth brightest object in the night sky is almost 26 times the size of our closest star.

The Sun is located at a mean distance of 150 million kilometres (93 million miles) from Earth, a distance known as one astronomical unit (1 AU). This giant nuclear furnace is composed mostly of ionised gas and drives the seasons, ocean currents, weather and climate on Earth. Over a million Earths could fit inside the Sun, which is itself held together by gravitational attraction, resulting in immense pressure and temperature at its core. In fact, the core reaches a temperature of about 15 million degrees Celsius (27 million degrees Fahrenheit), hot enough for thermonuclear fusion to take place. The intense physical process taking place in the Sun produces heat and light that radiates throughout the Solar System. It's not a quick process, though; it takes more than 170,000 years for energy from the core to radiate outwards towards the outer layers of the Sun.

Our Sun is classified as a yellow dwarf star and these stars range in mass from about 80 per cent to 100 per cent the mass of the Sun, meaning our star is at the upper end of this group. There are also three further groups into which stars are classified: Population I, II and III. Our Sun is a Population I star, which denotes that it contains more heavy



The magnetic field lines of the Sun extend out for millions of miles from its surface

elements compared to other stars (although still accounting for no more than approximately 0.1 per cent of its total mass). Population III stars are those that formed at the start of the universe, possibly just a few hundred million years after the Big Bang, and they are made from pure hydrogen and helium. Although hypothesised, no such star has ever been found, as the majority of them exploded as supernovae in the early universe and led to the formation of Population I and II stars, the latter of which are older, less luminous and colder than the former.

By now you're probably thinking our Sun is insignificant, but that's anything but the case. Being our closest star, and the only one we can study with orbiting telescopes, it acts as one of the greatest laboratories available to mankind. Understanding the Sun allows us to apply our findings to research here on Earth, such as nuclear reactors, and our observations of distant stars. Over the next few pages we'll delve into the reasons why studying the Sun is so important and explore some of the amazing physics going on inside and outside this vast nuclear furnace. ■

“The core reaches a temperature of about 15 million degrees Celsius, hot enough for thermonuclear fusion to take place”

## The planets in relation to the Sun

All figures = million miles from Sun





## Spicules

These supersonic jets of hot plasma form in the Sun's interior and rise to a height of around 5,000km (3,000 miles) above the Sun's photosphere

## Coronal mass ejections

A coronal mass ejection (CME) is a burst of plasma and magnetic fields, known as stellar wind, being thrown into space from the Sun's corona

## Faculae

Produced by concentrations of magnetic field lines, these bright spots appear on the Sun's chromosphere in regions where a sunspot will form

## Granulation

The Sun often appears granulated in images because of convection currents in its photosphere and chromosphere

## Prominences

These large loops of energy extend outwards from the Sun's corona. They can range over 700,000km (430,000 miles), approximately the radius of the Sun

## Sunspot

These dark spots on the surface of the Sun are caused by intense magnetic fields and are usually accompanied by a solar flare or CME

## Layers of the Sun

### Photosphere

The visible surface of the Sun, the photosphere, has a temperature of 5,530°C (9,980°F) and is made mostly of convection cells, giving it a granulated appearance

### Inner core

Most of the Sun's fusion power is generated in the core, which extends outwards from the centre to about a quarter of the Sun's radius

### Corona

The outer 'atmosphere' of the Sun. It is made of plasma, extends millions of kilometres outwards and has a higher temperature than the inner photosphere

### Chromosphere

This thin layer about 2,000km (1,240 miles) thick sits just above the photosphere and is the area where solar flares and sunspots are visible

### Radiative zone

This area is full of electromagnetic radiation from the core that bounces around as photon waves. It makes up about 45 per cent of the Sun

Our Solar System is located in the outer reaches of the Milky Way galaxy, which has roughly 200 billion stars





# Solar storms

Like the Earth, the Sun has an atmosphere, but the two are very different. The Sun's can be incredibly volatile with powerful magnetic activity that causes phenomena referred to as solar storms here on Earth

Solar storms are violent outbursts of activity on the Sun that interfere with the Earth's magnetic field and inundate our planet with particles. They are the result of outpourings of energy from the Sun, either in the form of a Coronal Mass Ejection (CME) or a solar flare. The former is a release of a large amount of material, mostly plasma, from the Sun while the latter is a sudden release of electromagnetic radiation commonly associated with a sunspot. While no direct connection has been found between CMEs and solar flares, both are responsible for

causing solar storms on Earth. The reason why these two events occur is due to the Sun's atmosphere and its turbulent interior, with all of its components playing a part in bathing our planet in bursts of energy.

The lowest part of the atmosphere, the part directly above the Sun's radiative zone, is the photosphere. This is the visible part of the Sun that we can see, it is 300-400 kilometres (180-240 miles) thick and has a temperature of about 5,530 degrees Celsius (9,980 degrees Fahrenheit). This produces a white glow although

from Earth this usually appears yellow or orange due to our own atmosphere.

As you travel through the photosphere away from the Sun's core the temperature begins to drop and the gases become cooler, in turn emitting less light. This makes the photosphere appear darker at its outer edges and gives the Sun an apparently clearly defined outer boundary, although this is certainly not the case as the atmosphere extends outwards much further.

Once you pass through the photosphere you enter the

chromosphere, which is about 2,000 kilometres (1,240 miles) thick. The temperature rises to about 9,730 degrees Celsius (17,540 degrees Fahrenheit), surpassing that of the photosphere. The reason for this is that the convection currents in the underlying photosphere heat the chromosphere above, producing shock waves that heat the surrounding gas and send it flying out of the chromosphere as tiny spikes of supersonic plasma known as spicules.

The final layer of the Sun's atmosphere is the corona. This huge

## Solar wind and the Earth

### Solar wind

Aside from solar flares the Sun is continually emitting radiation and particles in all directions in the form of solar wind

### Solar flare

The formation of a pair of sunspots on the Sun's surface creates a magnetic field line loop, which can in turn snap and send a violent eruption of material spewing out

### Magnetosphere

As these particles travel towards Earth they encounter the magnetosphere of our planet and travel along the magnetic field lines

### Aurora

Particles from the Sun can excite and heat particles at the poles of Earth, forming fantastic displays of light known as the aurora borealis and aurora australis in the north and south respectively





Particles ejected from the Sun can cause fantastic light displays at Earth's poles, known as the aurora borealis (or Northern Lights) and the aurora australis (or Southern Lights)

"Once you pass through the photosphere you enter the chromosphere, which is about 2,000km thick"

expanse of material can stretch as far as several million miles outwards from the surface. Oddly, the temperature of the corona averages 2 million degrees Celsius (3.6 million degrees Fahrenheit), far hotter than that of the photosphere and chromosphere. The reason for this is unknown; as far as we are aware, atoms tend to move from high to low temperatures and not

vice versa, so the process of material moving out of the Sun beyond the photosphere is not understood.

On the photosphere, dark and cool regions known as sunspots appear in pairs as a result of intense magnetic fields. The magnetic fields, caused by gases moving in the Sun's interior, leave one sunspot and enter another. Sunspot activity rises and falls on an 11-year cycle, as discussed in the next section. Sometimes clouds of gases from the chromosphere will follow these magnetic field lines in and out of a pair of sunspots, forming an arch of gas known as a solar prominence. A prominence can last up to three months and may extend up to 50,000 kilometres (30,000 miles) above the surface of the Sun. Once they reach their maximum height they break and erupt, in turn sending massive amounts of material racing outwards through the corona, an event which is known as a coronal mass ejection (CME).

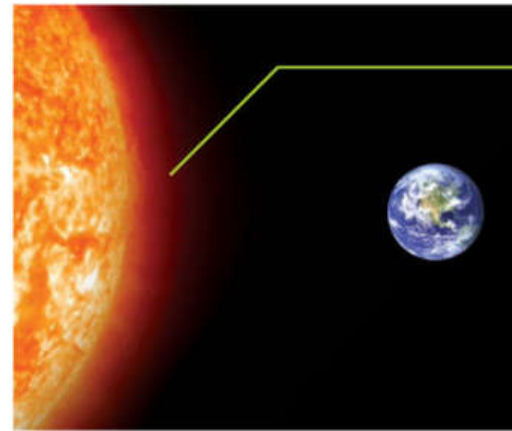
When the sun's magnetic field is concentrated in sunspot areas, the resultant magnetic field lines can extend and snap, causing a violent explosion on the surface of the Sun called a solar flare. At the moment of eruption vast amounts of radiation are emitted into space, which we call a solar storm when it reaches Earth. The particles within a solar storm often interact with particles in the atmosphere of planets in the Solar System, causing fantastic displays of light at their poles as the gases in the planet's atmosphere are heated by the particles. On Earth we know these as the aurora borealis in the Northern Hemisphere and the aurora australis in the Southern Hemisphere. ■

#### ■ Poles

The particles ionise the atmosphere of the Earth, particularly at the poles where they have followed the magnetic field lines

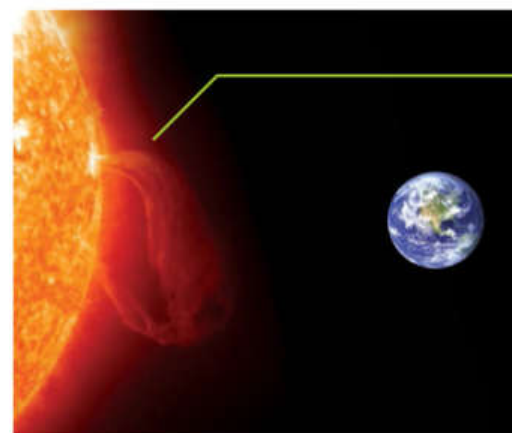
## How solar storms work

Vast amounts of radiation heading for Earth



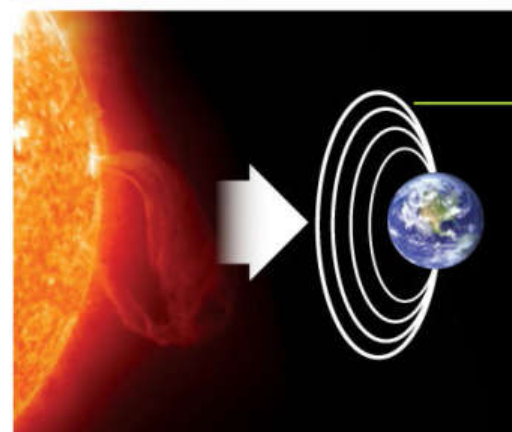
#### ■ Explosion

A solar flare can release up to  $6 \times 10^{25}$  joules of energy as it explodes from the surface of the Sun. The giant clouds of radiation and particles can take up to two days to travel to the Earth



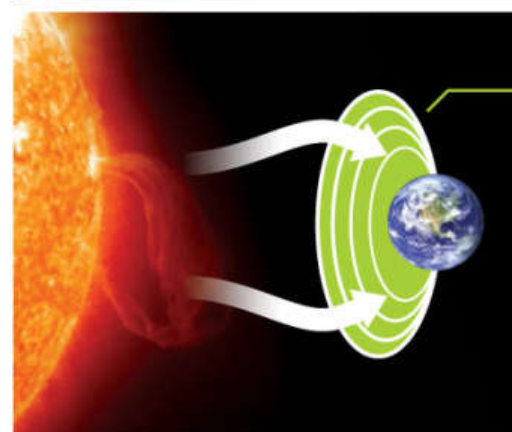
#### ■ Cycle

Solar flares peak in 11-year-long activity cycles. The cause of these cycles is unknown. In periods of inactivity there can be less than one flare a week but when the Sun is at its busiest there can be several every day



#### ■ Intensity

Solar wind typically travels at 1.6 million kph (one million mph), but the explosive event that emits a solar flare can send it hurtling towards the Earth up to four times faster



#### ■ Magnetosphere

The magnetic field surrounding the Earth acts as a barrier from the Sun's activity, but some of the particles travel along the magnetic field lines and excite particles in our atmosphere, in turn causing auroras to form at the poles



# The solar cycle

Our Sun is ever-changing, affecting all life on Earth and our natural environment

Our Sun may be a great distance away but its fluctuations and perturbations are still felt here on Earth.

Every 11 years the Sun moves from a period of low activity, known as a solar minimum, to a period of high activity, known as a solar maximum, and back again. When it is at its most active the Sun is even more violent than usual, with a greater number of sunspots appearing on its surface and therefore more solar flares emitted into space. During its minimum point it is still a raging inferno firing material into space but, by comparison, it is much quieter and sunspots, and therefore solar storms, are rare.

Cycles are observed by monitoring the frequency and position of sunspots on the Sun. When the Sun reaches the end of its cycle, new sunspots will appear near the equator. The beginning of the next cycle will see sunspots appear at higher latitudes on the surface of the Sun.

Solar cycles have been observed for centuries, but a standardised method of counting them was not devised until 1848 when Johann Rudolf Wolf started counting sunspots on the solar disk and calculated the Wolf number, which is still used today to keep track of the solar cycle. Cycles vary in their intensity. From 1645 to 1715 there were few sunspots present on the Sun, a period known as the Maunder Minimum. The number of sunspots has been relatively more uniform this century, with cycles having an average period of 10.5 years. The Sun also has a 22-year magnetic cycle where, every 22 years, its magnetic field flips from pole to pole. This doesn't have a noticeable effect on the Solar System, but indicates when the solar maximum of the current cycle has been reached. However, the reason for these cycles remains a mystery. No one yet has any clear understanding as to why the Sun has periods of varying activity. ●

## 1994-1996

As the Sun's activity began to wane, the number of sunspots per year dropped from about 100 per month in 1994 to 75 in 1996

## 1991-1993

At the start of this solar cycle there were about 200 sunspots on the surface of the Sun per month

## 10 years of the Sun

These X-ray images were taken by Japan's Yohkoh Solar Observatory and show the changes in the Sun's corona over a ten-year cycle between 30 August 1991 and 6 September 2001



"Solar cycles have been observed for centuries, but a method of counting them was not devised until 1848"

1997-1998

The Sun reached its period of solar minimum between these years, falling to almost zero sunspots per month

1999-2001

The Sun's activity increased again to a solar maximum, with up to 175 sunspots appearing per month

#### The Scientist's view

##### How we understand solar cycles

"Sun-Earth interaction is complex, and we haven't yet discovered all the consequences of solar cycle variation on Earth's environment. We saw a large amount of geomagnetic activity driven by recurring fast solar wind streams during the recent solar minimum. A surprising departure from the consistently low activity we'd come to expect from previous minima, especially considering the record low level of sunspots. These new observations deepen our understanding of how solar quiet intervals affect the Earth and how and why this might change from cycle to cycle."

Sarah Gibson, UCAR, @AtmosNews



## The Sun by numbers

Fantastic figures and surprising statistics about our nearest star

99.86%

*The Sun's percentage of mass of the entire Solar System*

Less than 5%

of stars in the Milky Way are brighter or larger than the Sun

1 million Earths  
Would fit inside the Sun

164 watts  
*Is the amount of energy every square metre of the Earth's surface receives. That's the equivalent of a 150-watt table lamp on every square metre of the Earth's surface*

498 seconds  
How long it takes light to travel from the Sun

100 BILLION  
TONS of dynamite would have to be detonated every second to match the energy produced by the Sun



# The SOHO mission

The Solar and Heliospheric Observatory was launched in December 1995 and is helping us explore the Sun

## Interview



SOHO  
project  
scientist  
Bernhard

Fleck tells us why studying the Sun is important to Earth

### 1. Understand life

"The Sun provides the energy for all life on Earth. It seems quite natural that we are curious to know more about the star from which we live."

### 2. Understand climate

"Solar radiation is the dominant energy input into the terrestrial ecosystem. The Sun provides a natural influence on the Earth's atmosphere and climate. To understand mankind's roles in climate change, the Sun's impact must be understood."

### 3. Predict space weather

"Our Sun is very dynamic and produces the largest eruptions in the Solar System. These solar storms can reach our planet and adversely affect technologies such as satellites and power grids. Space weather becomes increasingly important as our society depends more on modern technologies."

### 4. Learn about stars

"If we want to understand the universe, we have to understand the evolution of galaxies. To understand galaxies, we need to understand the evolution of stars that make up the galaxies. If we want to understand stars, we better understand the Sun, the only star we can resolve in great detail."

### 5. Stellar physics lab

"The Sun lets us study basic physical plasma processes under conditions that can't be reproduced on Earth."

The Solar and Heliospheric Observatory, also known as SOHO, was launched on 2 December 1995. It was built in Europe by prime contractor Matra Marconi Space, which is now EADS Astrium. The spacecraft is operated jointly by the ESA and NASA. It studies the Sun in depth, all the way from its deep core to its outer corona and its solar wind.

SOHO is made of two modules, the Service Module and the Payload Module. The former provides SOHO with power, while the latter houses all of the instruments on the spacecraft. Overall, there are 12 instruments on board SOHO, nine of which are run by Europe as well as three from the United States.

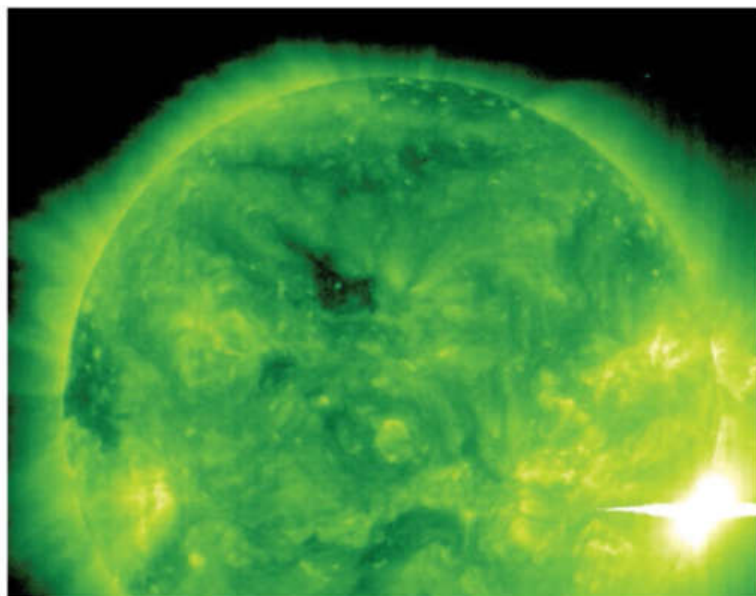
SOHO is located near to Lagrangian point 1, which is a point between the Earth and the Sun about 1.5 million kilometres (930,000 miles) from our planet. It is the point where the gravitational attraction of the Sun and the Earth cancel out, so a telescope such as SOHO can remain in a stable orbit to observe the Sun. SOHO is one of the only telescopes currently

capable of detecting incoming solar flares that could be potentially hazardous to satellites and other electronics on Earth.

Of the 12 instruments on board SOHO one of the most interesting is the Large Angle and Spectrometric Coronagraph (LASCO), which studies the Sun's corona by creating an artificial solar eclipse. The LASCO instrument has been largely responsible for inadvertently discovering many comets near the Sun, with over 1,800 found to date.

SOHO has three primary objectives that it has been carrying out since its launch. One of these was to investigate the outer regions of the Sun, specifically the corona.

At the moment it is still unknown why the corona is hotter than the photosphere and chromosphere of the Sun, so it is hoped that SOHO might help to provide the answer in the future. SOHO has also been used to observe the solar wind, and also to study the interior structure of the Sun through a process known as helioseismology. ■



On the scale of solar flares, X-class storms are most powerful. SOHO took this image on November 2003 showing the most powerful ever recorded, which reached X28

## Take a tour of SOHO

SOHO is made up of two modules.

The Service Module forms the lower portion, while the Payload Module sits above

### Payload Module

This sits on top of the Service Module and houses all 12 of the instruments on board the spacecraft

### Service Module

The Service Module provides power, telecommunications, thermal control and direction to the spacecraft

### Malfunction

In 1998 SOHO suffered a major malfunction that almost rendered it unusable.

However, some smart thinking enabled scientists to regain control of the telescope, although it now operates without the help of its gyroscopes, the only three-axis stabilised spacecraft to do so



### Mission Profile

Solar and Heliospheric Observatory (SOHO)

**Mission dates:** 02/12/95-12/12/14

**Details:** SOHO is a joint project between the ESA and NASA. It was designed to study the origin of the solar wind, the outer atmosphere of the Sun and its internal structure. SOHO has found over 1,800 comets to date and discovered that quakes on the Sun's surface are caused by solar flares. It has also made the most detailed map of features on the solar surface.

#### Antennas

SOHO transfers data back to Earth at a rate of between 40Kbits/s and 200Kbits/s using its high and low gain antennas

#### Solar panels

SOHO's only source of energy is from the Sun, but as it is in orbit around it, it has a large supply of energy

#### LASCO

SOHO's Large Angle and Spectrometric Coronagraph (LASCO) produces detailed imagery of the solar corona by creating an artificial eclipse



The SOHO spacecraft has survived 17 years in space, 15 more than its initial mission length

"SOHO is located near to Lagrangian 1, which is a point between the Earth and the Sun about 1.5 million km (930,000 miles) from our planet"



# Observing the Sun

Humanity has been fascinated by the Sun for thousands of years and even primitive records still prove useful. Discover more about the past, present and future of studying the Sun

Observations of the Sun have been used for both scientific and religious observations for millennia. Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC, while scientists such as Galileo studied the Sun through telescopes to discern some of its characteristics.

At the Chankillo archaeological site in Peru can be found the oldest solar observatory in the Americas, a group of 2,300-year-old structures used to track the motion of the Sun known as the Thirteen Towers. These towers provide a rudimentary solar calendar through which the Sun can be traced.

The towers, each between 75 and 125 square metres (807 and 1,345 square feet) in size, run from north to west along a ridge along a low hill. From an observation point to the west of the ridge the Sun can be seen to rise and set at different points along the ridge, which allowed ancient civilisations to track the number of days it takes the Sun to move from tower to tower.

Much later, in 1612, the renowned Italian astronomer Galileo Galilei (1564-1642) used his telescope to make one of the first observations of sunspots on the surface of the Sun. In 1749 daily observations began at the Zurich Observatory and, since 1849, continuous observations have been made to count the number of sunspots

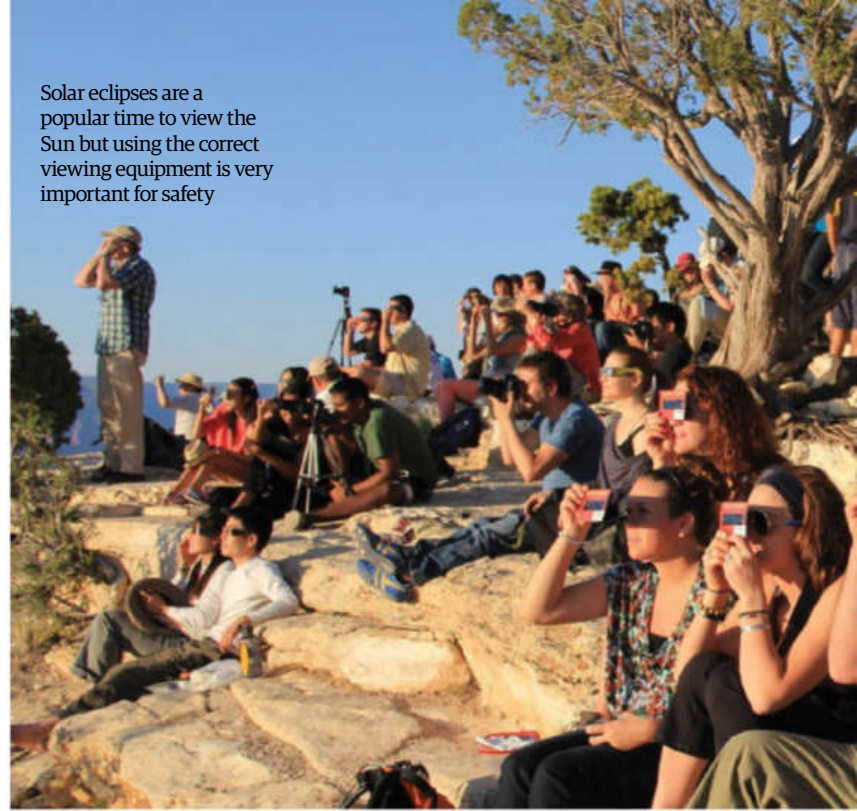
present on the Sun's surface at any one time.

Fast forward to today and, aside from SOHO, one of the primary telescopes used to observe the sun is the Japanese Hinode spacecraft. Hinode is a telescope in sun-synchronous Earth orbit, which allows for nearly continuous observation of the Sun. It was launched on 22 September 2006 and was initially planned as a three-mission study of the magnetic fields of the Sun, but its mission has since been extended as it continues to operate nominally.

Another important Sun-observing telescope is the Solar Dynamics Observatory (SDO), launched by NASA in 2010. The goal of the SDO is to study the influence of the Sun near Earth, predominantly how the Sun's magnetic field is responsible for the solar wind once it is released into the heliosphere. It should help scientists further understand the Sun's influence on the Solar System.

In the future, NASA's Solar Probe Plus will be the closest spacecraft to

Solar eclipses are a popular time to view the Sun but using the correct viewing equipment is very important for safety



the Sun, approaching to within just 8.5 solar radii (5.9 million km, 3.67 million miles, 0.04 AU) after its launch in 2018. It will probe the outer corona of the Sun in unprecedented detail, while also becoming the fastest spacecraft of all time in the process at up to 200km per second (120 miles per second).

Apart from million dollar telescopes, many amateur astronomers around the globe today observe the Sun either for entertainment or educational benefit. Using specially designed glasses people can look at the Sun from Earth, although caution must be taken to limit time spent looking at the Sun and it should never be looked at with the naked eye. Other methods of solar observation include using a

telescope to produce a trace of the Sun, a method similar to that used by Aristotle and his camera obscura in the 4th Century BC. Again, precautions must be taken here, as under no circumstances should the Sun be directly observed through a telescope.

Whatever the method, and whatever the mission, observations of the Sun have been a long tradition and will continue to be so for the foreseeable future. Astronomical events such as planetary transits and solar eclipses provide amateur astronomers with opportunities to see extraordinary solar phenomena, while agencies throughout the world will continue to study the Sun and learn more about how the fantastic star works. ●

“Civilisations have used the Sun to keep an accurate count of days, months and years since at least 300BC”



**400BC**

The world's oldest solar observatory, the Thirteen Towers of Chankillo, is built in Peru to track the motion of the Sun.



**350BC**

Aristotle uses a camera obscura to project an image of the Sun and observe a partial eclipse.



**1612**

Galileo Galilei uses his telescope to make one of the first observations of sunspots on the surface of the Sun.

## The history of observing the Sun

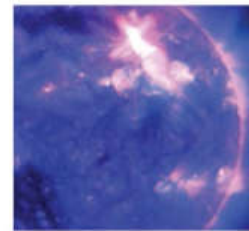




## Different ways to observe the Sun

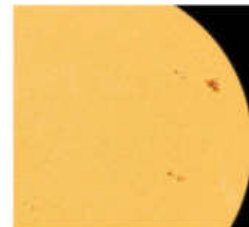
On Earth we perceive the Sun to be a yellow ball of gas in the sky but, like anything as hot as the Sun, it is actually closer to being white hot when viewed from space. There are several telescopes currently observing the Sun but

the large majority of our images come from the STEREO telescope and the SOHO observatory, both in orbit around the Sun. By viewing the Sun in different wavelengths we can study its different characteristics and see some of its main features in a different light.



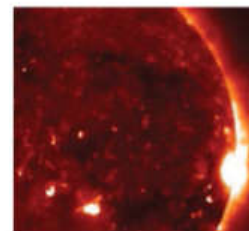
### Ultraviolet

Images of the Sun in ultraviolet light are between wavelengths of about 19.5 and 30.4 nanometres. Such an image of the Sun is at the lower end of this scale, and allows us to see where the lower part of the corona and upper part of the chromosphere combine. The light in this image comes from active regions in the Sun's chromosphere.



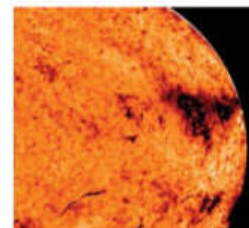
### Visible

Visible light images commonly refer to those viewing the Sun in white light, which shows the true colour of the white-hot Sun. In visible light images we can see the Sun's photosphere, which is about 6,000 degrees Celsius (10,832 degree Fahrenheit) and therefore appears white-hot. Here, we can see dark spots on the surface of the Sun, known as sunspots.



### X-ray

Light with a wavelength shorter than ten nanometres (ten billionths of a metre) is known as X-ray light. X-rays are emitted from the Sun's corona, the hottest visible layer of the Sun's atmosphere. The visible areas of brightness are places where more X-rays are being emitted, around areas of increased activity on the Sun's surface.



### Infrared

Infrared light is responsible for more than half of the Sun's power output, typically around wavelengths of 1,080 nanometres. Infrared images show features of the Sun's chromosphere and corona. The dark features on the image are areas where the gas is more dense, absorbing more infrared light than in other areas.



A telescope with a digital screen can be used to safely observe the Sun



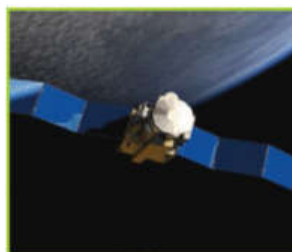
1749

Daily observations of the Sun begin for the first time at the Zurich Observatory in Switzerland.



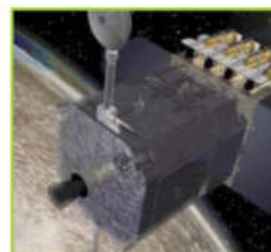
1849

New observatories around the world allow continuous observations of sunspots to be made.



2006

The Japanese telescope Hinode is launched to study the magnetic fields and atmosphere of the Sun.



2010

NASA launches the Solar Dynamics Observatory, its primary goal being to study the influence of the Sun near Earth.



2018

NASA's new Sun-observing telescope Solar Probe Plus will launch and become the closest spacecraft to the Sun.



# The Moon

The most visible celestial object from Earth has been the source of human fascination for millennia, yet we're still discovering more about it all the time

Orbiting at a distance of anywhere between 362,570 kilometres and 405,410 kilometres (225,000 to 252,000 miles) and moving away from the Earth at almost four centimetres (1.57 inches) per year, all 74 billion trillion kilograms (160 billion trillion pounds) of blasted grey rock that is the Moon never fails to make for fascinating viewing. Its topography is a pattern of 'maria' - impact basins once filled with lava - and giant craters that are clearly visible from Earth.

Most notable of these is Tycho on the near side of the Moon. Despite being around 86 kilometres (53 miles) in diameter and 4.8 kilometres (three

miles) deep, it's not the largest of the Moon's impact features: that accolade goes to the South Pole-Aitken basin on the far side, which is 2,500 kilometres (1,550 miles) in diameter, 13 kilometres (eight miles) deep and one of the biggest craters in the Solar System. But with its distinctive ray system fanning out for hundreds of kilometres across the surface in all directions, Tycho is the Moon's most recognisable feature.

We're still learning about the Moon, the most recent major mission being the Gravity Recovery and Interior Laboratory (GRAIL) mission that generated the highest resolution gravity map of any celestial body. ●









# MOON COLONIES



"America's challenge of today has forged man's destiny of tomorrow," said Apollo 17 astronaut Gene Cernan as he stepped back into the Lunar Module with fellow astronaut Jack Schmitt on 14 December 1972. The Apollo missions were expected to kickstart an age of human space exploration including lunar colonies, manned Mars missions and possibly ventures beyond. But four decades later, and the pipe dreams of 20th Century visionaries seem further away than that fateful first step in 1969.

It's no exaggeration to say that, in the year 2012, many had predicted space to be teeming with human life. The fact that it's not, save for a handful of astronauts aboard an orbiting space station, is a disappointment to many a space enthusiast. But is it really all doom and gloom? Are we truly destined to remain constrained to our Blue Planet, left to observe the Moon from afar rather than setting foot, and living, where only a dozen men have done so before?

"If something can be done, it ultimately will be done," says Dr Paul Spudis, talking to us about the possibility of a future Moon settlement. "If at some point it makes sense for the Moon to be permanently inhabited, then it will happen."

Dr Spudis is somewhat of an expert when it comes to lunar exploration. He is currently a senior staff scientist at the Lunar and Planetary Institute in Houston, Texas, and has worked on both the Indian Chandrayaan Moon programme and NASA's Lunar Reconnaissance Orbiter. He also served on a White House panel to analyse a return to the Moon and the establishment of a lunar base.

From the outside looking in a possible Moon colony might seem improbable, if not impossible, but it's an idea that has been suggested by scientists since the dawn of the space age, including Dr Spudis himself.

"I advocate a return to the Moon to use it for the creation of a new space-faring capability," says Dr Spudis. "That essentially means that we hope to extract the material and energy resources of the Moon to build a permanent, space-faring capability. In practical terms that means, initially, the extraction of water from the deposits near the lunar poles and its use for a variety of purposes, mostly rocket propellant but also human life support and power storage. Eventually, we can build structures from lunar materials, but water is the easiest and most useful substance to get at first."

As the 40<sup>th</sup> anniversary of the last manned Moon mission passed in 2012, we investigated the progress being made towards establishing a permanent lunar base on the surface of our satellite



The reference of water on the Moon is an important one, and is one of the primary reasons that lunar exploration has become such an intriguing talking point once again. The discovery of water on the lunar surface was formally announced by NASA on 24 September 2009. Found by the Chandrayaan-1 orbiter and impact probe, it was a huge announcement with far-reaching ramifications.

As Dr Spudis mentions, water is a vital ingredient for any form of manned space exploration. It's essential for life, and its constituents (hydrogen and oxygen) also happen to be the primary components of rocket fuel. Previous visions of a lunar base envisioned a colony constantly resupplied by missions from Earth, a costly and timely endeavour that a multinational mission would struggle to accomplish, let alone one nation going it alone. The discovery of water on the Moon, hiding as ice in the shadowed and cold reaches of the deepest lunar craters, raised the very real possibility of a lunar colony being self-sustaining, rather than reliant on resupplies from Earth.

"Water on the Moon is the most important discovery for spaceflight since the rocket equation," explains Dr Spudis. "It means that we can learn how to 'live off the land' on the Moon, an essential skill for any space-faring species."

It's not quite as easy as landing on the Moon and scooping up bucketfuls of water, however. While water ice exists, its quantities are up for debate. The lowest estimates place it at making up just 0.00001 per cent of a portion of lunar soil, sparser than the driest deserts on Earth. Upper estimates suggest a quantity of 8.5 per cent, a much more useful amount if correct. In March 2010, Chandrayaan-1 again made an important discovery, this time finding 40 permanently darkened craters near the Moon's poles with a potential 600 million metric tons (1.3 trillion pounds) of water ice if the upper estimate holds true.

Dr Spudis highlights the need to quantify how much water ice is available to ensure the success of a lunar colony: "Although we know that water exists on the Moon, we have many questions about its physical state and how it varies in concentration. We need to prospect and map ice deposits, extract some water to determine how difficult it may be, and use it in space to completely demonstrate the use of lunar water from an end-to-end systems engineering basis."

Whatever the true quantity of water on the Moon, the possibility of colonising the Moon is not only exciting but also incredibly useful. From a purely financial perspective, the prospects might seem bleak. Estimates suggest a lunar colony would cost upwards of tens of billions of dollars, an amount of money simply not available to any space agency in the world. But the potential returns are huge, in the form of job creation, new inventions and better technologies. For every dollar invested in the Apollo mission, it is said that around 20 dollars were returned to the American economy. The prospect of a permanent residence on the Moon would only increase the potential return. And this is before we even consider the existence of helium-3 on the lunar surface, an isotope blasted across the Moon by solar wind that could be the key ingredient to creating fusion reactors, and therefore huge sources of power, on Earth.

Humanity is not just a species driven by money, though, despite what some would have you believe. We are inquisitive, curious, and we constantly strive to further understand the natural world around us and the universe as a whole. Confining ourselves to our world and failing to invest in manned space exploration would be akin to giving up on our natural habits, to learn, and would relegate us back to an age where humans merely looked upon the stars with fondness, rather than the thought that they could be explored.

## "Technically, we're not far away from returning man to the Moon and creating a Moon base"

**Dr Paul Spudis**, senior staff scientist, Lunar and Planetary Institute



## History of Moon exploration

### 3 Feb 1966 Luna 9

This Soviet 'craft was the first probe to land on the Moon and return surface images.



### 30 May 1966 Surveyor 1

The first successful unmanned American Moon landing returned 11,000 pictures.



### 20 July 1969 Apollo 11

Neil Armstrong and Buzz Aldrin were the first humans to set foot on the Moon.



### 11 Dec 1972 Apollo 17

While the last humans on the surface were Americans Gene Cernan and Jack Schmitt.



### 22 Aug 1976 Luna 24

This was the last spacecraft to date to land on the Moon and return lunar samples to Earth.



### 8 Nov 2008 Chandrayaan-1

This Indian probe found water on the Moon, and released an impactor to the surface.



## A small step - developing lunar bases

While NASA has long had a vision to create a manned station on the Moon, other agencies have also announced plans to return humans to the Moon for a prolonged period of time.

### China



The biggest emerging nation in space exploration,

China has made no secret of its desire to land humans on the Moon. It launched its first two unmanned probes in 2007 and 2010, with the third set to follow in 2013.

It has also carried out extensive manned operations in Earth orbit, with a manned space station to follow in the coming years. All of this is building towards a manned lunar landing and, possibly, a permanent residence on the Moon.

### Russia



Roscosmos, the Russian space agency, has a number of

unmanned landers planned to touch down on the lunar surface by the end of the decade, but work is also underway on a manned mission that will take Russians to the Moon for the first time. Four automated probes will land on the Moon by 2020, followed by a larger station in 2023. This station could be the first part of a manned lunar base in a polar region to follow at an unspecified date.

### India



The Indian Space Research Organisation (ISRO)

has announced rather lofty goals for space exploration, including a manned landing by 2020. While this looks unlikely for now, its intentions to return man to the Moon at some point are clear.

### Japan



The Japanese Aerospace Exploration Agency (JAXA) has

suggested that it wants to build a robotic base on the Moon by 2020. This would be a precursor to a manned lunar base in 2030.



## USA



Since the Apollo missions ended, NASA has been studying the feasibility and usefulness of returning humans to the Moon. The discovery of water ice has provided the added incentive that could result in the construction of a lunar base.

In September 2012, NASA deputy chief Lori Garver announced the agency's ambitions: "We're going back to the Moon, attempting a first-ever mission to send humans to an asteroid and actively developing a plan to take Americans to Mars."

NASA has carried out a lot of research into lunar habitation. From rovers to landers, it has tested important technologies that we'll need to return to our natural satellite.

### 1. Altair lunar lander

Now scrapped, Altair was once part of NASA's cancelled Project Constellation.

### 2. Lunar Electric Rover

This vehicle could house two astronauts at a time, and enable them to perform space walks on the Moon.

### 3. Project Morpheus

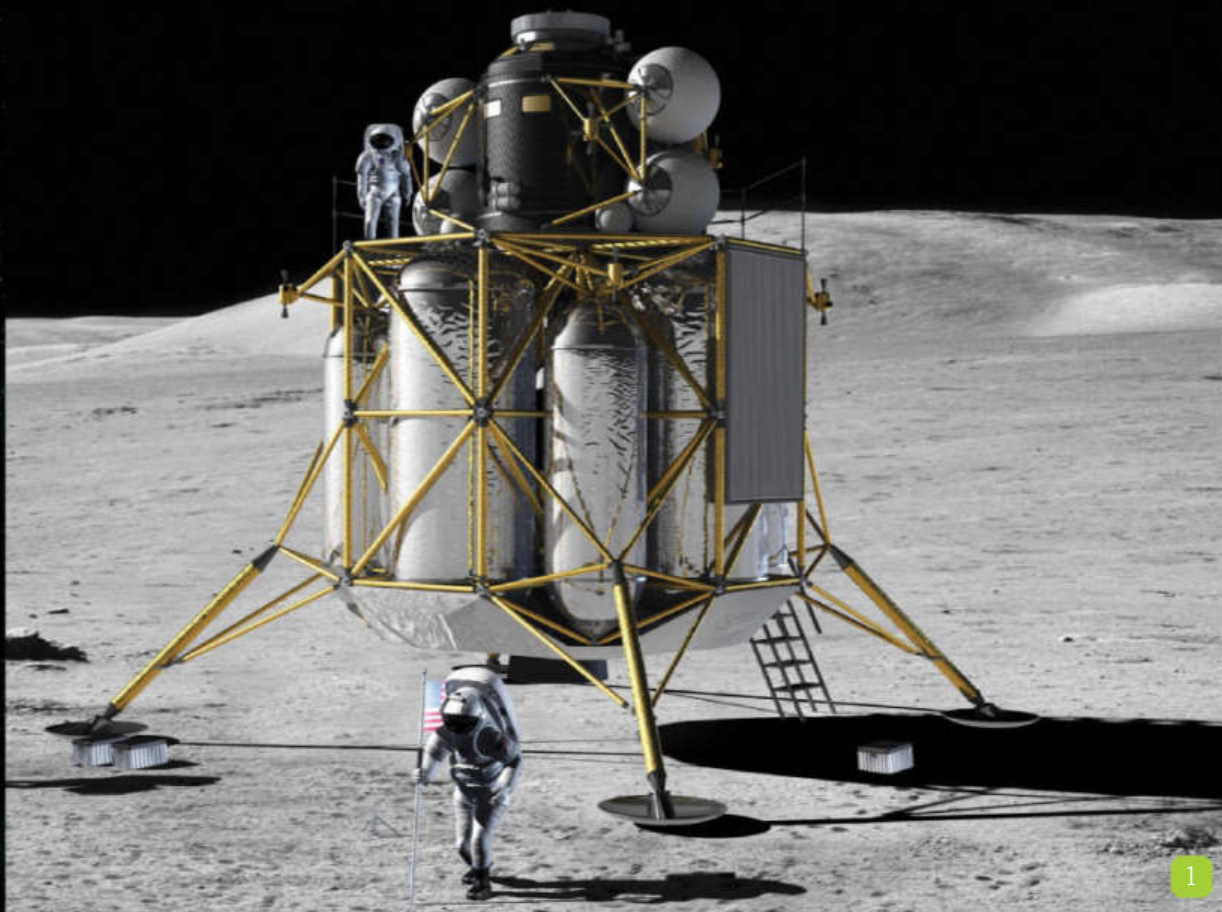
This automated NASA cargo vehicle, currently in the testing phase, would be used to transport up to 500kg (1,100lb) of cargo to the lunar surface.

### 4. Orion

The Orion Multi-Purpose Crew Vehicle could take man beyond low-Earth orbit to the Moon. It is also intended to be used to visit an asteroid and Mars.

### 5. Inflatable habitats

To save space on launch, NASA has been researching the possibility of taking inflatable habitats to the Moon.



1



2



3



4



5



## The giant leap – future plans for a Moon colony

By the end of the 21st Century a colony on the Moon is a realistic possibility. The technology for each component, from inflatable habitats to transport to and from the Moon, is already in development. Once we work out how to harness some of the Moon's most useful resources, settling on the lunar surface will become an attractive goal.

### Rovers

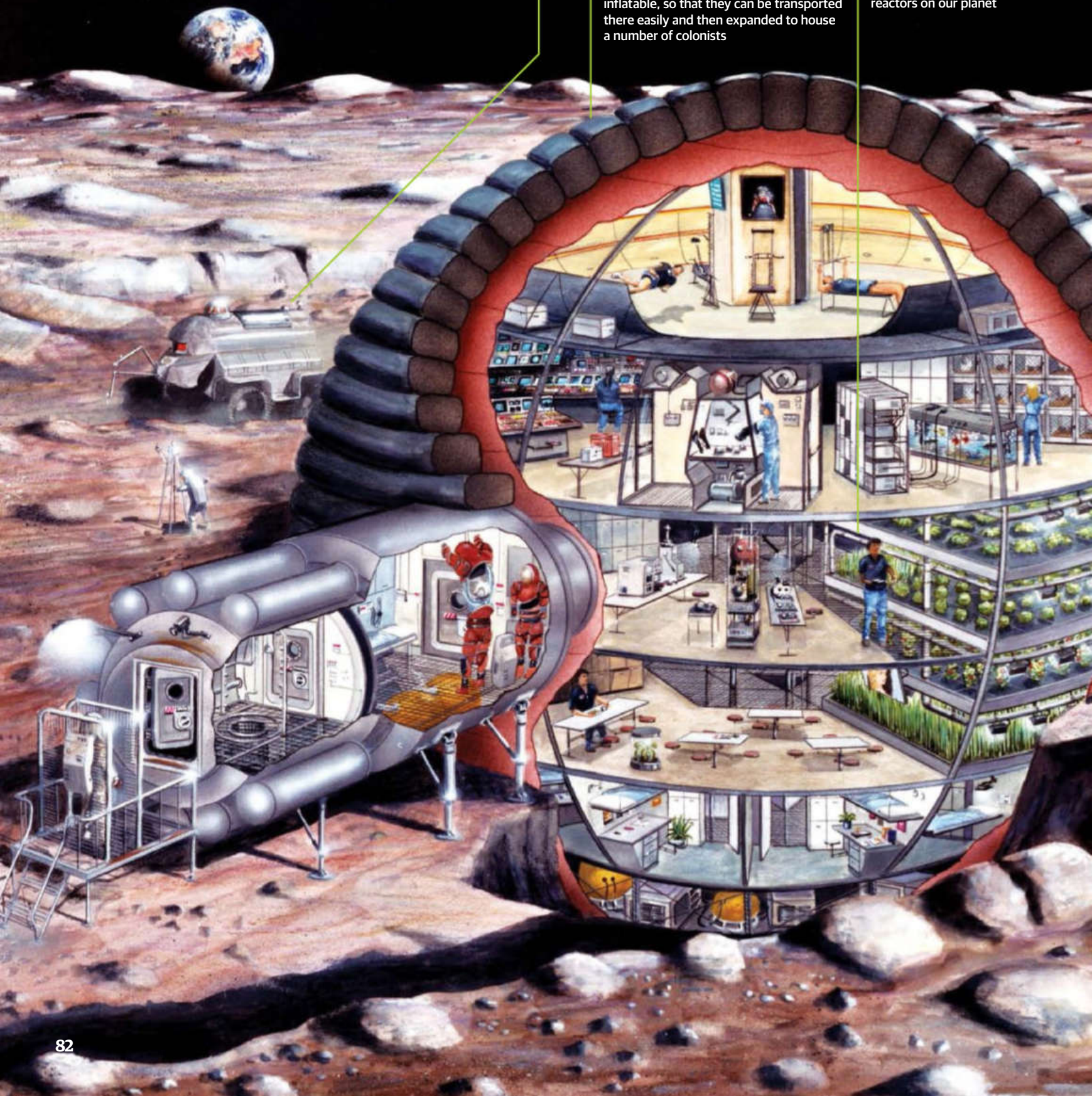
In order to explore vast swathes of the Moon, including water-rich craters, manned and unmanned rovers will be a necessity. Manned rovers could be mini habitats, allowing astronauts to survive on excursions away from the base for several weeks

### Inflatable stations

Habitats on the Moon will likely be inflatable, so that they can be transported there easily and then expanded to house a number of colonists

### Resources

Both water and helium-3 are the most useful resources on the Moon. Apart from drinking, the former could be used by the colonists to create fuel on the Moon, while the latter could be launched back to Earth to power futuristic fusion reactors on our planet







### Privatising the Moon

The best way to colonise the Moon might be to realise the commercial benefits of it, space settlement expert Al Globus told us. Globus has previously worked on the ISS from Earth and, alongside being chairman of the National Space Society's Space Settlement Advocacy Committee, he is a big proponent of space settlement and has written many papers on the subject.

By the end of the 2010s, Globus said, governments around the world will have a number of landers and orbiters on and around the Moon. The big change in manned space exploration, however, will be the huge growth of the private sector. Sub-orbital tourism (with the likes of Virgin Galactic) will take-off, with over 1,000 people a year reaching space by 2020.

The next two decades will see lunar mining companies begin to spring up on the Moon, he continued, although they could struggle financially at first. The key for their success will be the growth of the space tourism industry; even though the ISS will be decommissioned in the early 2020s, space hotels will be launched into Earth orbit and expand the private space sector. Over the next 50 years the number of space tourists could grow to millions, not just thousands.

This, Globus said, is where privatising the Moon will be key. Mining resources from the lunar surface, such as water, could provide essential supplies for these hotels. It'll take a while for lunar mines to become profitable, but by the 2070s they could be supplying most of the materials necessary for space hotels.

Furthermore, if NASA or another agency constructs a lunar mass driver on the Moon, which would allow for cargo to be sent back to Earth, then Globus said the lunar mining business will become extremely profitable, allowing it to potentially dominate the metal markets on Earth. In the 2050s these mines would need a crew of just 20 people, but by the 2080s there could be thousands of people living on the Moon and operating them.



#### Transport

Vehicles similar to the Apollo Lunar Module could transport astronauts to and from the Moon, while space cannons (or mass drivers) could launch cargo ships loaded with useful resources back to Earth

#### Communications

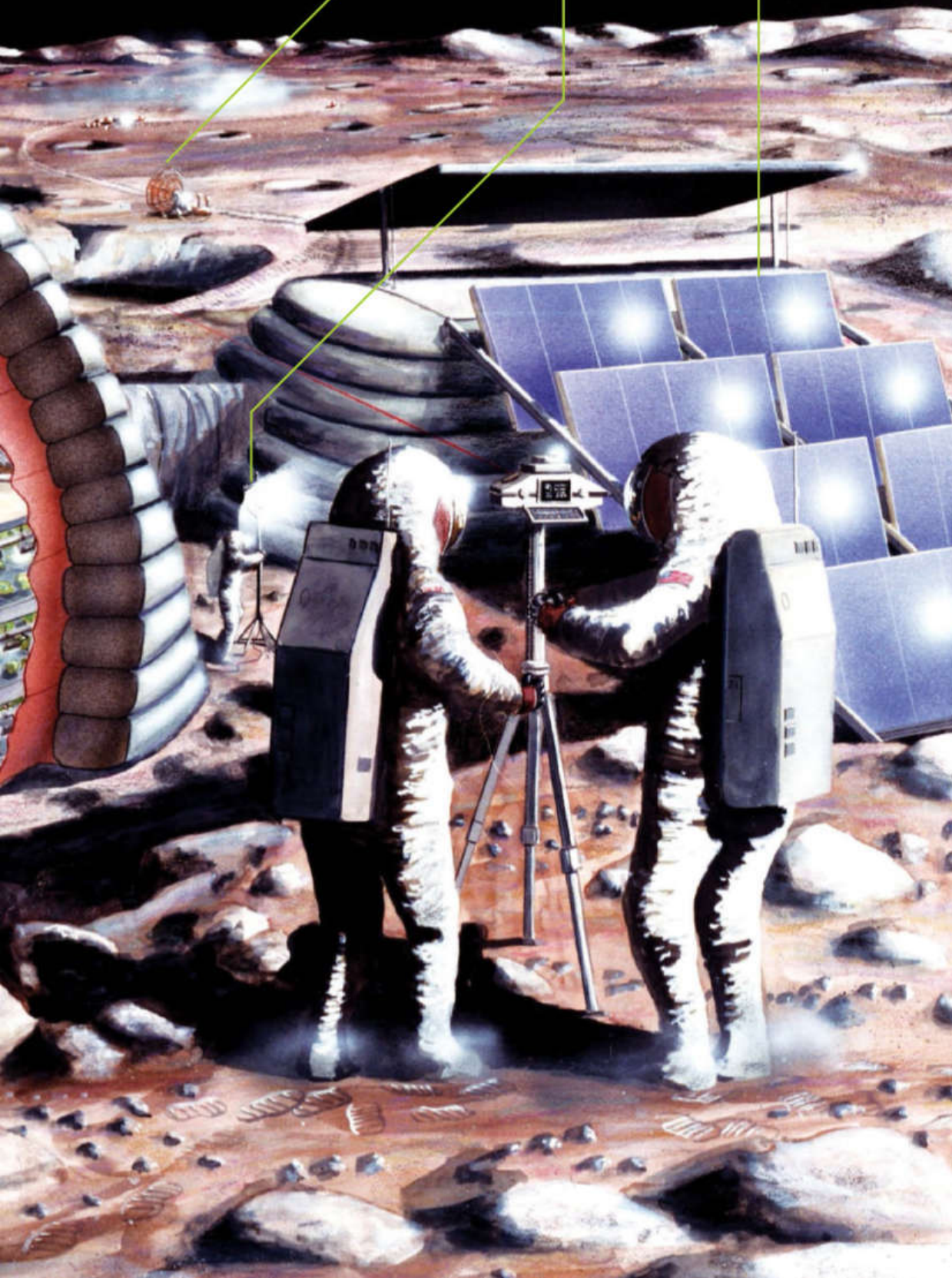
A colony based on the near side of the Moon will have no problems talking to Earth as they will always be in view, but a base on the far side (which would be useful for astronomy purposes, as there would be no radio interference from Earth) would need an orbiting spacecraft in order to phone home

#### Lights

Like on Earth, artificial lighting could be used on the Moon to enable operations to continue at night. As a day on the Moon lasts almost 30 Earth days, this will be vital

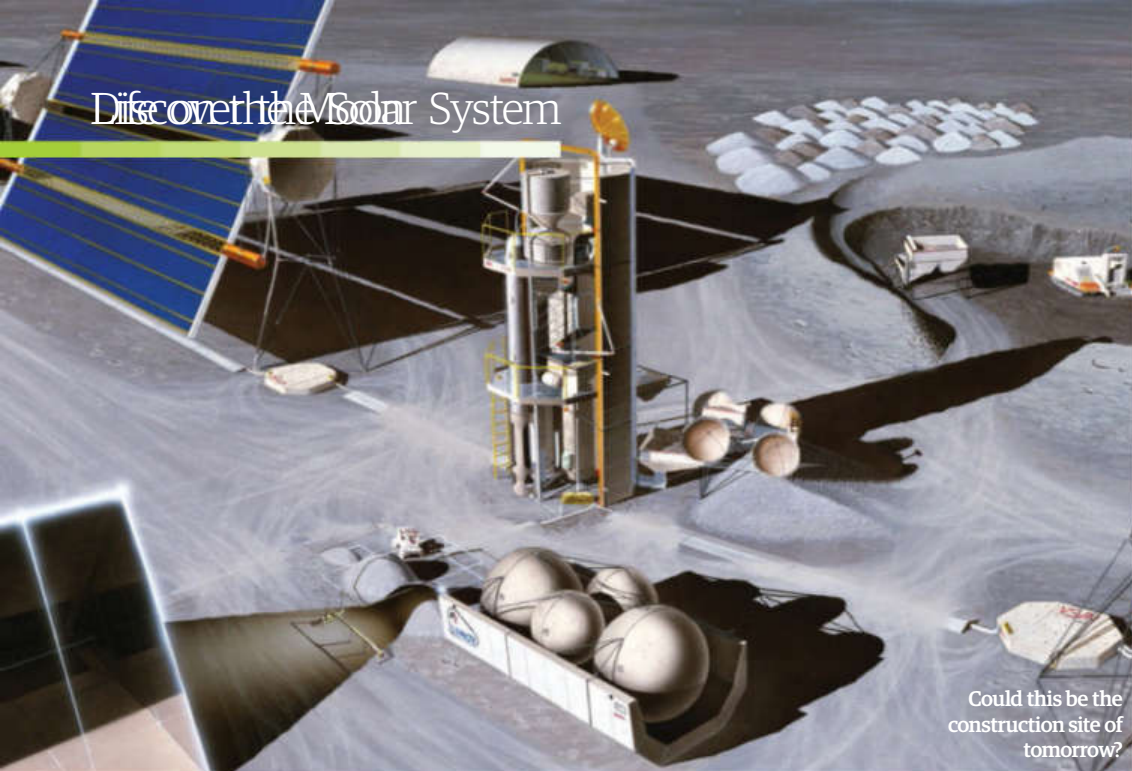
#### Solar

Many people incorrectly believe there's a 'dark side of the Moon', but that's not the case. The entire lunar surface is, at some point, bathed in sunlight (apart from darkened craters), so solar panels will be the main source of power for any lunar colony





## Discover the Solar System



Could this be the construction site of tomorrow?



The Apollo missions returned a lot of useful lunar rock

The colonisation of the Moon is a vital stepping stone in our grander scheme of exploration.

That's not to mention the constant threat our planet is under from extinction. It's easy to forget that just 65 million years ago, a mere 1.4 per cent of our planet's 4.5 billion year existence, an asteroid wiped out almost every living thing on the surface. We know that there's no impending impact event, but one is likely to occur at some point. With no other-world colonies to inhabit, we are doomed to extinction.

"The Moon serves as our first 'off-shore coaling station' on the ocean of space," agrees Dr Spudis. "We can use its material to fuel a permanent transportation system, one that allows us to not only access the Moon and explore it in detail, but more importantly, to routinely access all of cislunar space [the zone between the Earth and the Moon], where all of our satellite assets reside. The Moon is also a major scientific resource because it records in detail a period of Solar System history that has been erased from the Earth."

So, if we were to decide to build a lunar colony, could it be done?

**"From a policy perspective, we are light years away, mainly because few people recognise the value of the Moon"** **Dr Paul Spudis**

"Technically, we're not far away from returning man to the Moon and creating a Moon base at all," says Dr Spudis. "We have all the individual pieces and technology we would need to live and work on the Moon right now." Technology, however, is not the problem, explains Dr Spudis: "From a policy perspective, we are light years away, mainly because few people recognise the value of the Moon as I have described it here. I am trying to change those misperceptions."

Many agencies have carried out studies into the feasibility of a lunar colony, reaching as far back as 1959 when the US Army first established a plan to build a fort on the Moon with two astronauts. Known as Project Horizon, it would have required about 150 separate rocket launches, making it unattractive from a cost perspective.

Various proposals have followed, and in the 21st Century numerous countries have at least announced their intentions to build a base on the

Moon, including Japan, Russia and the USA. It is NASA, however, that has carried out the most research in the area. For example, it has been testing its Lunar Electric Rover for several years now and, while it might be repurposed for use on an asteroid rather than the Moon, it could provide weeks of habitation for astronauts on the Moon if deployed.

All forms of research, though, have focused on visits longer than the Apollo missions (so over three days) but not quite at a level of permanent habitation. As Dr Spudis explains, we still have problems to overcome if we are to colonise the Moon. "Although we understand how to extract and use lunar resources in theory, we have not done so in practice," he says. "The biggest need right now is experience: in accessing and surveying the ice deposits, in digging up the ice and processing it into water, in converting that water into its gaseous components, in cryogenically freezing

the gases into liquids and, finally, using the product in a variety of applications. We understand how to do all these things in theory, we simply need to learn to do them to learn where the problems are."

Overcoming these problems and testing key technologies are imperative goals if we are to achieve the ultimate dream of building a settlement or colony on the Moon. There's little doubt, however, that positive progress is being made in many of the necessary areas by several nations around the world.

Lunar colonies are not just the fancy of space visionaries any more; they will certainly play a useful and important role in our continued future exploration of the Solar System, and provide us with an off-world habitat the likes of which have never been seen before. "I believe that the Moon is a critical enabling step into the Solar System," says Dr Spudis. "It is a stepping stone to space capability." ■

Manned and unmanned vehicles could scour the Moon's surface



Astronauts would live in stationary lunar habitats



Many different components are needed for a lunar colony





# Road map to the Moon



NASA Johnson Space Center engineer John Connolly speculates on how he thinks lunar colonisation might develop.

## 2030-2039

The 2030s will see a continued buildup of an international science base near one of the lunar poles. 30-day missions with crews of four will mature to 180-day missions in which teams of pressurised rovers carry crews to more remote sites. Lunar resources will be in full use to provide the crews' oxygen, water, and the propellant for their return to Earth. The lunar surface will increasingly be used to test hardware that will be used for an upcoming human mission to Mars. In lunar orbit, or perhaps at an Earth-Moon libration point, the deep-space habitats and propulsion systems for the Mars mission will also be tested. The first lunar tourists will likely arrive in this decade.

## 2070-2079

The Moon becomes the stepping off point for human voyages to Mars and beyond. Due to its rich resources, and low gravity, the Moon becomes the choice for launching missions into deep space.



## 2050-2059

Lunar colonies begin to spring up at multiple locations around the lunar globe. 'Vacations' to the Moon, though still costly, become the top destination, with lunar 'hotels' beginning to emerge. The first child is born on another world.

## 2060-2069

Colonisation begins to increase, with distinct communities occupying different parts of the Moon. Like the Antarctic of 100 years earlier, different countries have established permanent outposts for scientific purposes, but other areas are being developed for commercial resource purposes and for residential communities.

## 2040-2049

Scientific exploration of the Moon begins to combine with commercial visits. Interest in lunar metals and resources fuels commercial missions to produce not only fuels and consumables to support lunar operations, but to extract high-value materials for export to Earth. Helium-3 mining, which occurs as a by-product of other resource extraction processes, reignites the interest in nuclear fusion as a clean power source for Earth.

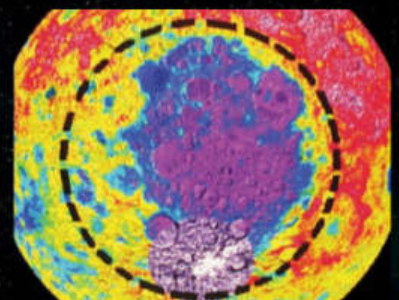
## 2020-2029

In the 2020s humans will return to the Moon. Lunar surface missions will become international partnerships, following on from the experience of the ISS, and multiple countries will raise their flags on the Moon. We will test in-situ resource utilisation at human-scales, producing water and propellants from lunar feedstock.



## 2010-2019

Leading up to the year 2020, the first private lunar lander will land on the Moon, likely to claim the Google Lunar X Prize. This may open up an entire new way of performing lunar science missions - with science agencies purchasing 'rides' for their instruments rather than funding the engineering of the spacecraft and purchase of launch vehicles. Lunar sample return missions will date the deepest known impact basin (South Pole-Aitken basin) and return samples of polar volatiles. Other robotic missions will probe the permanently shadowed craters of the lunar poles and test in-situ resource utilisation technologies.





# The rings of Jupiter

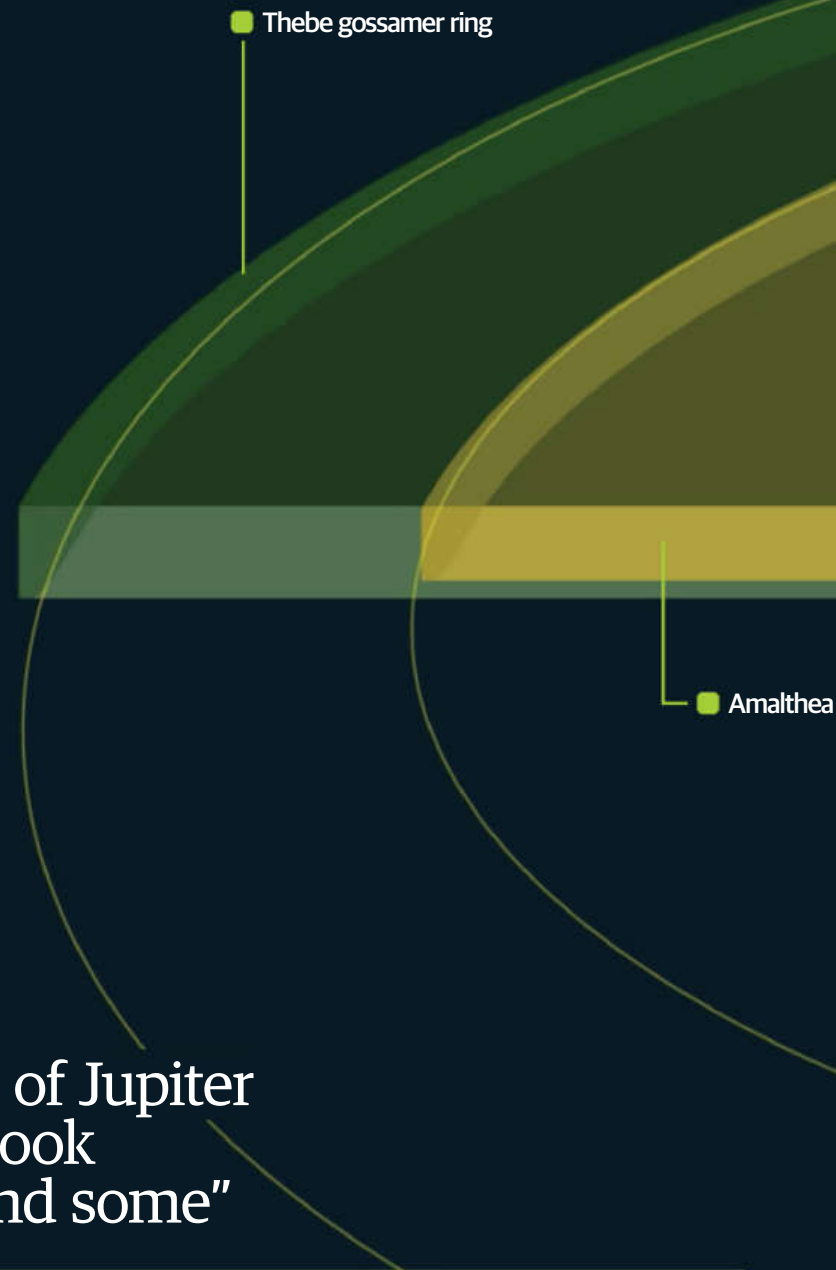
Did you know that Jupiter has rings like Saturn? Only recently have we been able to study them

The gas giants Jupiter and Saturn have been known about and observed since ancient history. During the Renaissance period and with the dawn of the telescope, Saturn was characterised by its mesmerising ring system whereas Jupiter was the hulking brute of the Solar System, known for the swirling tempest blooming on its south equatorial belt that was later dubbed the Great Red Spot. Scientists identified a similar ring system on Uranus, so when Voyager 1 began its flyby of Jupiter in early 1979, NASA tasked it to look specifically for rings – and it found some. Nearly 20 years later, the Galileo probe entered orbit around Jupiter and was able to study its rings in detail, while New Horizons was able to take high-resolution images revealing the structure of the main ring in its spring 2007 flyby.

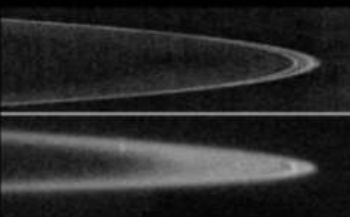
Jupiter's rings are made of four parts and are composed mainly of fine dust of varying grades. A thick

'halo' ring orbits the innermost Jovian region, followed by the bright main ring, and the two faint gossamer rings. These gossamer rings are made up of the dust ejected from the two moons, Thebe and Amalthea, which orbit within them, a result of high-energy impacts kicking up debris from their surfaces. The biggest of Jupiter's rings is the Thebe gossamer ring, which has a radius of around 226,000 kilometres (140,000 miles), a width of 97,000 kilometres (60,000 miles) and a thickness of 8,400 kilometres (5,000 miles).

The rings themselves might have existed as long as Jupiter, although the lifetime of the tiny dust particles in the main ring could be anything from 100 to 1,000 years. It's continuously being removed from the ring by the Jovian magnetosphere and replenished by impacts between larger objects that are anything from a single centimetre (0.4 inches) up to 500 metres (1,640 feet) in diameter. ●



“When Voyager 1 began its flyby of Jupiter in early 1979, NASA tasked it to look specifically for rings – and it found some”



## Planetary rings

There are several theories of how large planetary rings of this type are formed. One theory is that they're the remnants of the protoplanetary disc that formed the planet, left within a region that was unable to form a moon (known as the Roche limit). Another is that they're the remains of a moon either torn apart by the tidal stresses of large planets such as Jupiter, or destroyed by a massive impact. Smaller and fainter

rings can form from multiple impacts into the surface of moons orbiting a planet or from a volcanic eruption, such as the E-ring of Saturn, which formed out of the cryovolcanic ejecta from Enceladus's volcanoes. In around 50 million years' time, the Martian moon Phobos is likely to be pulled apart into a ring because of its low orbit. Since the discovery of rings around Uranus, Neptune and Jupiter, scientists have been looking closely at other celestial bodies such as the Saturnian moon Rhea and Pluto, to see whether they have rings, too.



## Ring breakdown

What are Jupiter's rings made of, how big are they and how were they formed?

### Halo ring

The innermost halo ring stretches from around 92,000km (57,000 miles) to just over 120,000km (78,000) and is the thickest of Jupiter's rings through the vertical. It's shaped like a torus and is significantly less bright than the main ring despite being many times wider and thicker. The dust particles that the Halo ring is composed of are less than 15 micrometres in diameter and are mostly derived from the main ring.

### Main ring

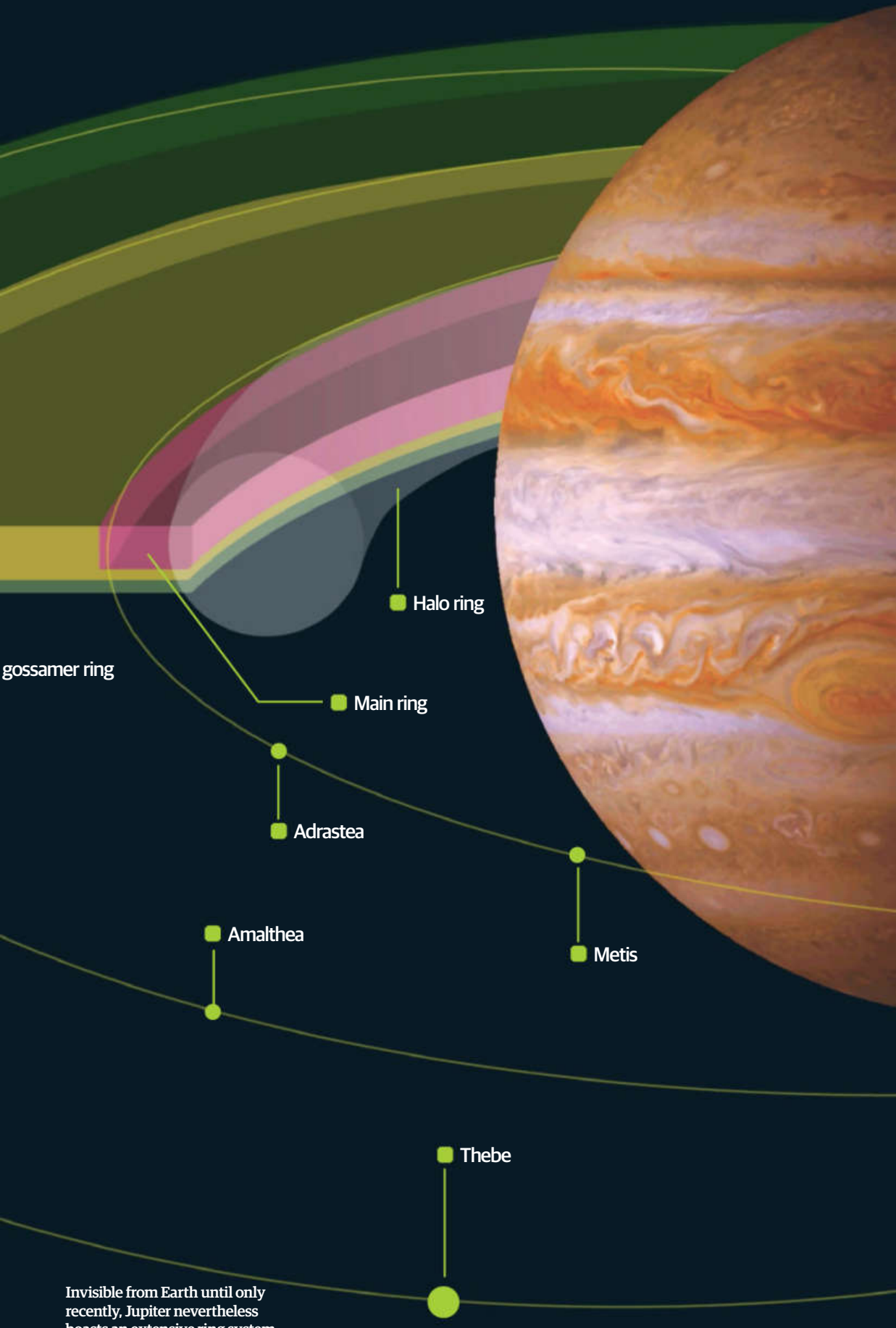
This narrow ring is just 6,500km (4,000 miles) wide and stretches from 122,500km (76,000 miles) and 129,000km (80,000 miles). It's the brightest of the rings and fringes on Adrastea, the smallest of Jupiter's four inner moons. The main ring's dusty composition isn't evenly distributed and is divided into regions of varied thickness that scatter light more effectively than the other rings. Still, it was faint enough to be missed by the Hubble Space Telescope and wasn't detected until Keck viewed it in 2002.

### Amalthea gossamer ring

The innermost gossamer ring runs from the border of the main ring to around 182,000km (113,000 miles), decreasing in thickness towards Jupiter. The ring gets its name from the Jovian moon Amalthea, a 160km (99 mile) diameter rock that orbits right through the centre of the Amalthea gossamer ring. As it passed through the gossamer rings in 2002, the Galileo spacecraft detected small bodies of less than 1km (0.6 miles) near Amalthea, which are likely the debris caused by numerous collisions.

### Thebe gossamer ring

Like Jupiter's other rings, the Thebe gossamer ring is composed of dust from impacts with the Jovian moons. It's the faintest of the rings and stretches far out to the orbit of the moon of Thebe at 226,000km (140,000 miles). However, scientists are unable to explain the extension of the Thebe ring's orbit, which could be due to the influence of Jupiter's magnetosphere or even objects on the outside of the Thebe ring that are as yet unseen.



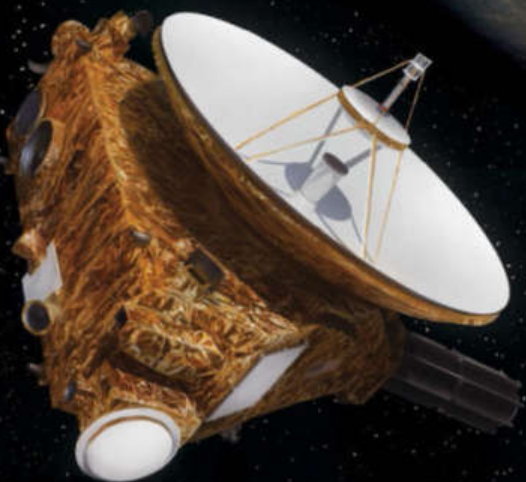
Invisible from Earth until only recently, Jupiter nevertheless boasts an extensive ring system



# PLUTO

## Our Last Frontier

Pluto has long interested astronomers but it has never been explored by space probes... until now





It has been on a breathtaking journey 4.8 billion kilometres (3 billion miles) long. It has taken nine-and-a-half years. And it has cost \$700 million (£460 million). But for patient astronomers working on the New Horizons mission, the spacecraft which is about to make the first-ever reconnaissance of Pluto is more than worth its half-ton weight in gold.

Launched on 19 January 2006, New Horizons is set to spend this summer flying by Pluto and its five known moons. It is already the closest man-made object to Pluto, but very soon it will be within a space whisker and scientists are very excited about the possible discoveries it will enable them to make.

"Imagine the explorers of old who crossed the oceans," says Dr Alan Stern, the principal investigator of the New Horizons mission. "They will have had some of the same feelings we are having after their long journeys. I just tell people, if you are anything like me then you will fasten your seat belt because I expect that you will be in for one heck of a ride."

Pluto's history has already been on something of a rollercoaster. Hypothesised by US astronomer Percival Lowell in the early 1900s, it was finally discovered by Clyde W Tombaugh on 18 February 1930. A month later, this object believed to be the ninth planet was officially named, but it was stripped of its planetary status by astronomers in 2006.

Today Pluto is classified as a 'dwarf planet' since its highly elliptical orbit overlaps with that of Neptune. But that matters little to Dr Stern and his team at the Southwest Research Institute, which was granted the mission by NASA following an open competition in 2001. For, regardless of its status, Dr Stern views New Horizons as a giant leap forward. "At one point we even considered naming the mission One Giant Leap," he reveals. And he firmly believes the wait will be worth it: "Space missions are usually over in less than nine years but ours is only just beginning."

To get ready for the mission, Dr Stern and his team had to work fast. As soon as they were chosen to head the mission, they knew they needed a Jupiter gravity assist if they were to get to Pluto within nine-and-a-half years. "But that meant getting this built and launched in four years and two months because the Jupiter gravity assist that we used to go to Pluto was the last one for a decade," he says. It represented a record: Cassini-Huygens, which was sent to Saturn, took a decade to be built, as did Galileo, which studied Jupiter. In order to achieve it, the team worked nights and weekends for four years straight.

The results have been impressive, though. Five times less expensive than Voyager, New Horizons has not relied on the invention of new spacecraft technology but it has a good set of seven instruments

on board. "We put all of our technology into better cameras, better spectrometers, more capability to return data," says Dr Stern. In February 2007 as New Horizons swung past Jupiter for a gravity boost, the team was able to test the spacecraft systems and instruments on a practice flyby. More than 100 scientific papers using data from the Jupiter flyby were published and it also made the cover of *Science* magazine. When asked what he expects to find on Pluto, though, Dr Stern laughs: "If I knew, I wouldn't have to do the mission."

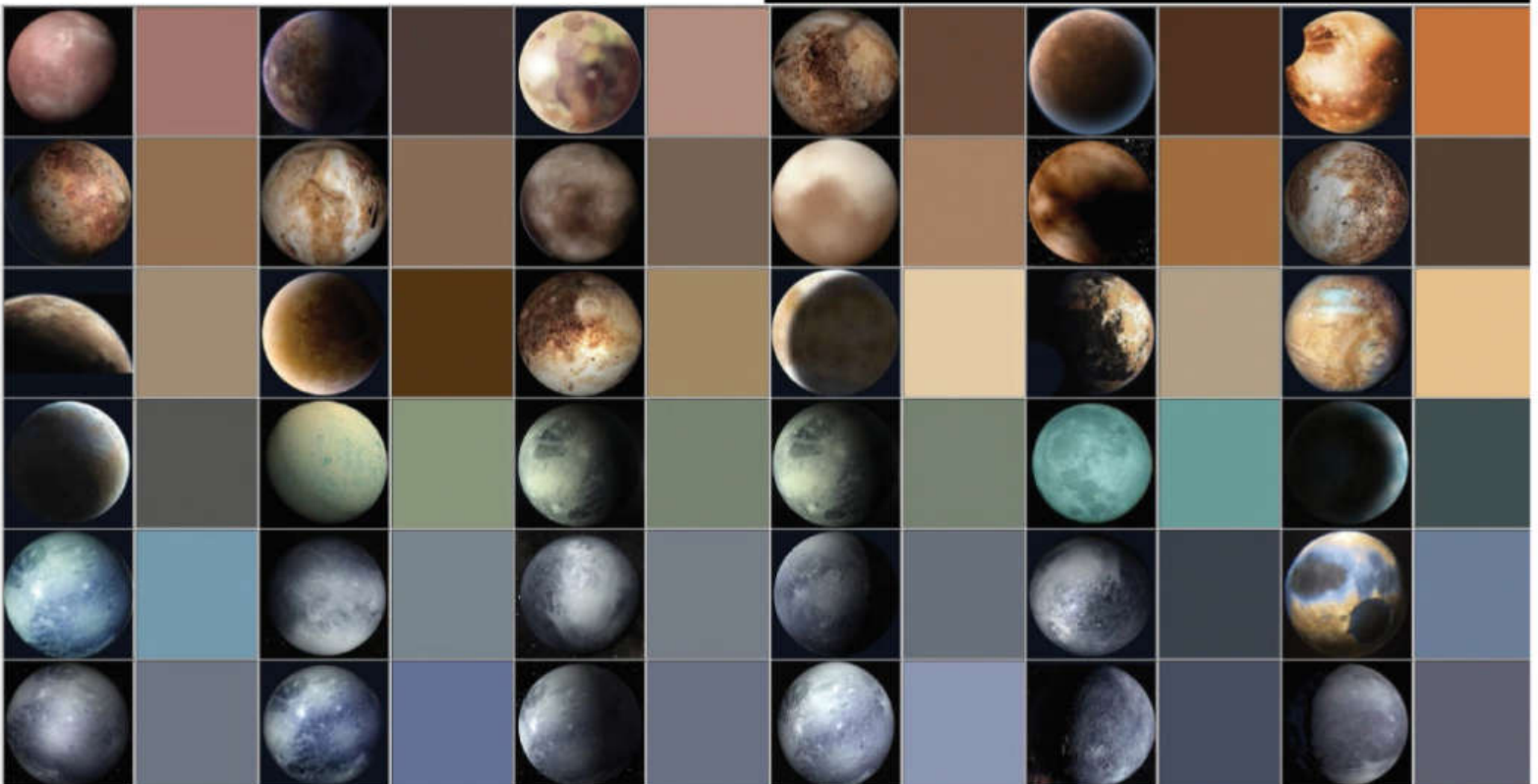
New Horizons came out of hibernation for the last time on 6 December 2014 as it made its final



"I just tell people, if you are anything like me then you will fasten your seat belt because I expect that you will be in for one heck of a ride"

**Dr Alan Stern, New Horizons principal investigator**

Created by astrophysicist Alex Parker using 60 unique images to represent Pluto from the internet, the chart below estimates typical colours for the dwarf planet





## Passengers to Pluto

NASA has sent slices of humanity – as well as Pluto's discoverer – into space



### Photos

A CD-ROM containing images of the people who have worked on New Horizons has been added to give the mission a personal touch.

### Commemorative coin

A Florida state quarter – a commemorative coin released by the United States Mint between 1999 and 2008 – pays homage to the spacecraft's Cape Canaveral Air Force Station launch site.



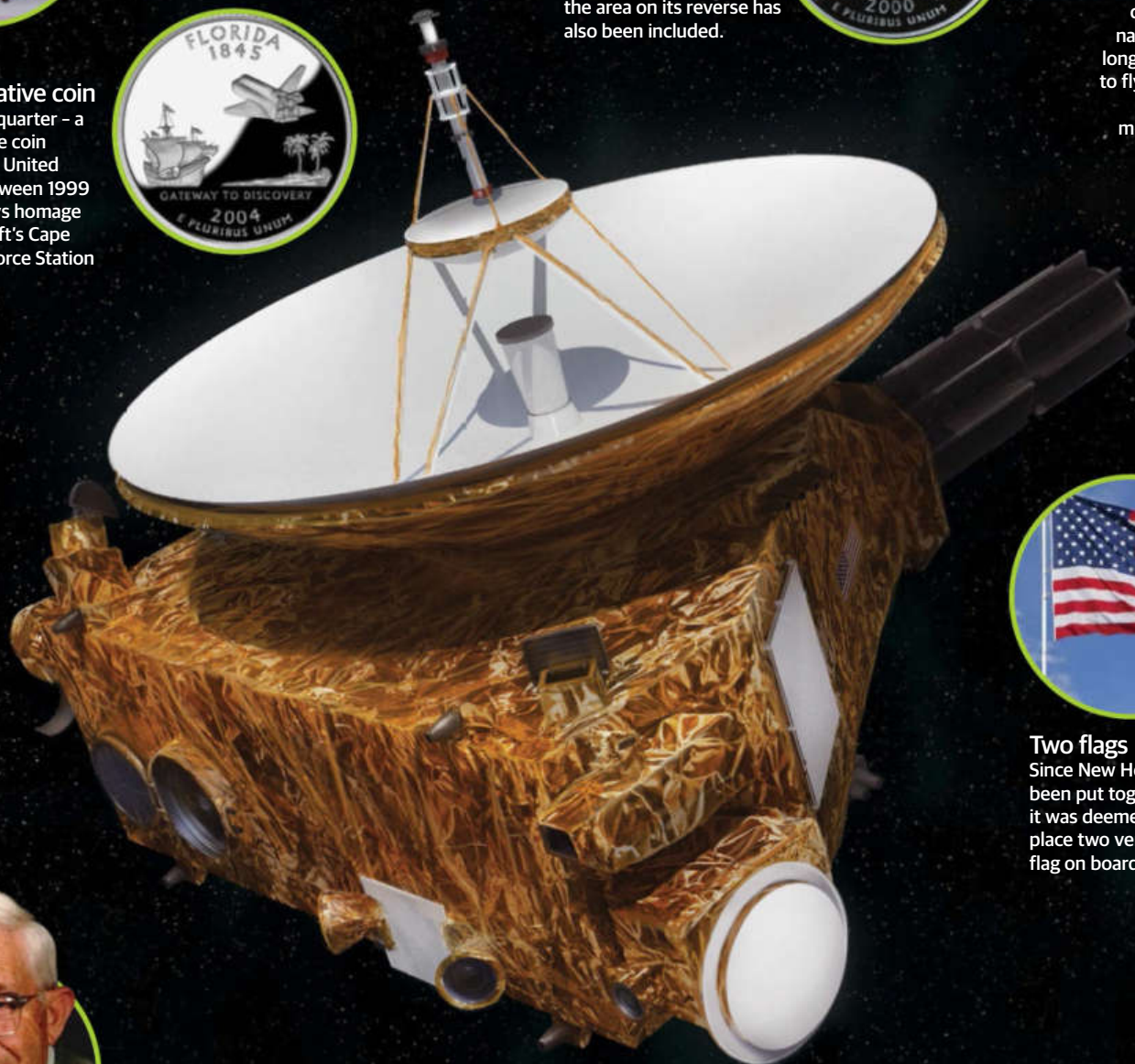
### Maryland Quarter

New Horizons was built in the US state of Maryland and so a commemorative quarter with a design depicting the area on its reverse has also been included.



### People's names

Mounted on the exterior of the New Horizons spacecraft is a CD-ROM containing 434,738 names, maintaining a long-standing tradition to fly a full list of active Planetary Society members into space.



### Two flags

Since New Horizons has been put together by NASA, it was deemed fitting to place two versions of the US flag on board.



### Founder's ashes

Clyde Tombaugh, who discovered Pluto, is going along for the ride – or at least a portion of his ashes are. They are stored underneath the spacecraft in a container.



### SpaceShipOne

On the lower inside deck of New Horizons is a small piece cut from SpaceShipOne, a suborbital air-launched spaceplane that completed the first manned private spaceflight in 2004.



### Collectible stamp

NASA has been recognised by America's Citizen's Stamp Advisory Committee on more than 36 stamps since 1967. One, in 1991, carried the words 'Pluto: Not Yet Explored', and is on board New Horizons.



# Fastest missions

How does New Horizons compare to other speedy spaceships?



## Space Shuttle

**28,000km/h (17,500mph)**

The Space Shuttle must reach these speeds in order to remain in orbit between 306km (190mi) and 531km (330mi) above sea level. It carries two solid rocket boosters.

## New Horizons

**58,536km/h (36,373mph)**

New Horizons is the fastest spacecraft ever launched. The initial propulsion gave it enough speed to carry it to Pluto, assisted by a boost from Jupiter's gravity.

## Juno

**257,500km/h (160,000mph)**

Juno's mission to Jupiter passed around Earth, giving it an acceleration boost akin to the propulsion of a second rocket launch. On arrival at Jupiter in 2016, gravity will increase speeds further.

approach. Since then it has observed Pluto for an entire 6.4 Earth-day rotation, watching it wobble slightly thanks to the gravity of its largest moon, Charon. It has also revealed a large bright area at the pole of Pluto. The science team cannot know for certain what it is until the composition is tested but it suggests the presence of a polar cap. With broad dark and bright regions across the icy world, even at a distance of 113 million kilometres (70 million miles), it was viewed as a major discovery.

"Pluto showed dramatic markings, telling us that it is a special place; that is different from most of the others especially because only the Earth has had anything similar," says Dr Stern. When the spacecraft gets closer, things will become even clearer. That's when discoveries will be made at a rate of knots with astronomers keen to find out if there are other possible moons and even whether there are rings around Pluto.

"If we did see rings then what we could conclude would depend on what we found, the number and locations and densities of them, but it would be exciting," says Dr Stern. "The possibilities are many." Indeed, there are many mysteries waiting to be found and explained: the surface composition is said to include nitrogen, carbon monoxide, methane and

water ices, for instance, but many other materials may be present and undiscovered.

There is even a possibility, no matter how small, of life. Pluto is two-thirds rock and one-third water in the form of water ice. It has more than three times as much water as all of the Earth's oceans. If either have an ocean, meaning the water would be warm enough to be liquid, there could theoretically be life on Pluto or Charon. If that was the case they would, like Saturn's moon Enceladus and Jupiter's moon Europa, go on the list of potential astrobiological targets.

What is just as fascinating is that, during the five months it will spend observing Pluto close-up, the dwarf planet will barely have moved. Pluto only orbits the Sun once every 248 Earth years but it's not the only focus of New Horizons' mission. Its secondary objective is to make the first exploration of the small bodies in the disc-shaped Kuiper belt region, which Dr Stern says "turns out to be the largest class of planet in the Solar System."

The Kuiper belt contains bodies of mainly ice and rock. But there are potentially trillions of Kuiper belt objects, hundreds of thousands of them believed to be larger than 100 kilometres (62 miles) in size, plus many, many more as small as one kilometre (0.62 miles). Eris is one of the icy worlds and several of

the dwarf planets have tiny moons. "There are more known Kuiper belt planets than there are gas giants and terrestrial planets combined," says Dr Stern. "So this is a very important new and unexplored class of targets in the Solar System."

Pluto remains the primary focus, though. As New Horizons approaches, the spacecraft's dust and charged particle instruments have been taking measurements. Operating every day and sending home data every week, they have been telling scientists about Pluto's wider environment. When scientists get close-up data, they will be able to interpret it in context.

"It has confirmed models of the expected dust density but that was no surprise," says Dr Stern. "It has amplified on the kind of information that the Voyager spacecraft obtained when it went through the Kuiper belt. The instrumentation that we are carrying to study the solar wind and other charged particles is vastly more sensitive, so we can see many more details. Even this far from the Sun, the spacecraft is crossing interplanetary shocks, supersonic shocks in the solar wind, which Pluto also crosses - and so do the other Kuiper belt objects. So we are just characterising the space weather environment out there."



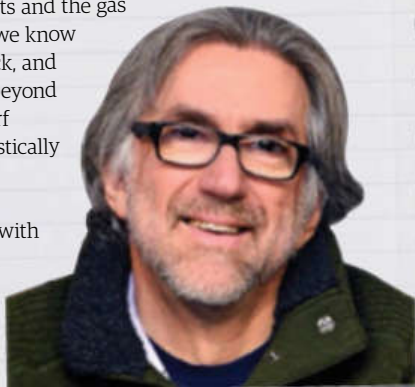
# Is Pluto still a planet?

Leading experts give their views on the controversial decision to downgrade Pluto to a dwarf planet in 2006

## YES

**Dr William B McKinnon, professor at the Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University in St Louis**

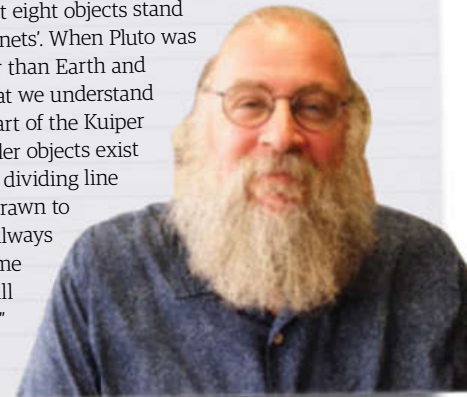
"Pluto is a planet. But it is a small, or dwarf, planet. It is the exemplar of an entirely new class of planets, the other classes being the rocky terrestrial planets and the gas giants. All of the dwarf planets we know of so far are made of ice and rock, and most reside in the Kuiper belt, beyond Neptune. But the idea that dwarf planets are not planets is linguistically sloppy and a bit silly. Planetary scientists study bodies, not just masses and orbits, and a world with five moons, an atmosphere and hints of a complex history, is planet enough for most of us."



## NO

**Dr Hal Levison, planetary scientist specialising in planetary dynamics at the Space Studies Department of the Southwest Research Institute**

"Scientists typically classify objects into groups based on natural boundaries. [When looking at] the size and orbits of objects in the Solar System, it's clear the largest eight objects stand apart and deserve the name 'planets'. When Pluto was discovered, it was thought larger than Earth and isolated, hence a planet. Now that we understand that Pluto is small and simply part of the Kuiper belt. Many Pluto-sized and smaller objects exist there, and so there is no natural dividing line between. If a line is artificially drawn to make Pluto a planet, there will always be two objects of almost the same size and appearance, but one will be a planet and the other won't."



## Definition of a planet



### It has to orbit the Sun

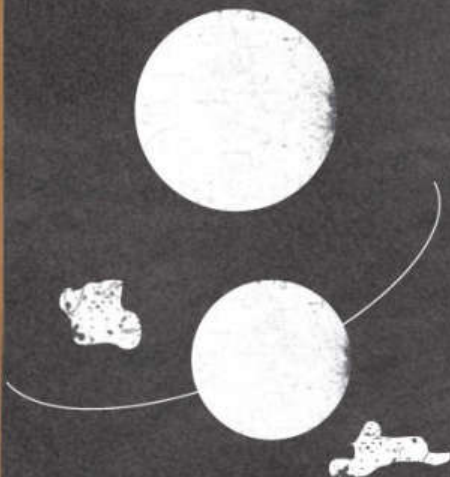
The Sun is the centre of the Solar System and it pulls planets into a curved orbit. The International Astronomical Union says this is a fundamental definition for a planet.

### It must be round (ish)

If the celestial body has sufficient mass so that its own gravity squashes it into a ball that is as round as possible, it assumes a planetary - hydrostatic equilibrium.

### It needs its own space

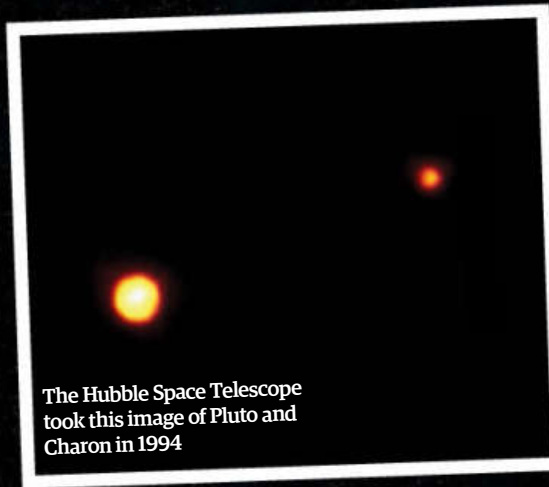
That is, it must clear the neighbourhood around its orbit. It means the body has become gravitationally dominant with no other comparably sized bodies in its vicinity.



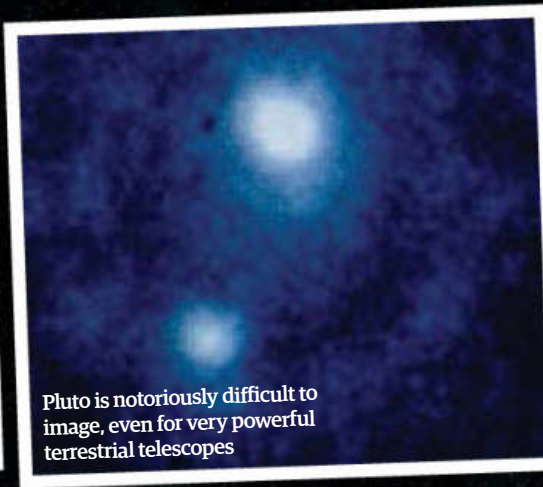


## Imaging a distant, cold dwarf planet

From clear shots of its moons to a possible polar cap, Pluto is revealing itself bit by bit



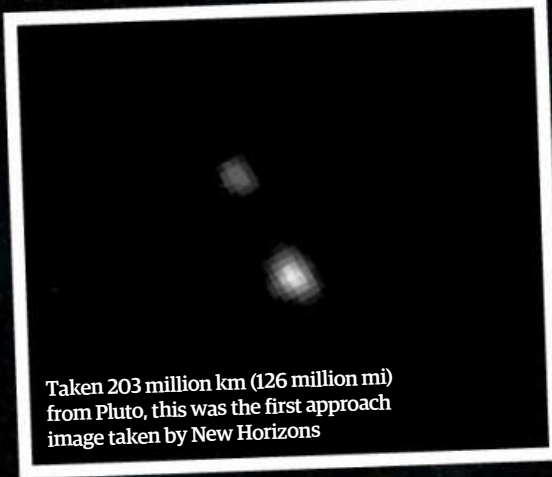
The Hubble Space Telescope took this image of Pluto and Charon in 1994



Pluto is notoriously difficult to image, even for very powerful terrestrial telescopes



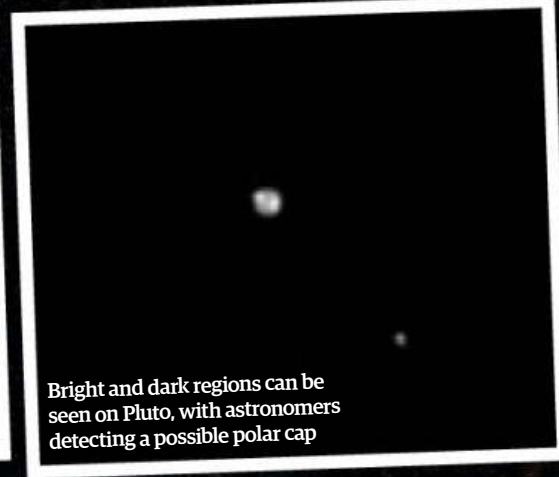
The Pluto-Charon System, taken by the European Southern Observatory's Very Large Telescope



Taken 203 million km (126 million mi) from Pluto, this was the first approach image taken by New Horizons



Pluto and its largest moon, Charon, on 9 April - captured in colour for the first time by New Horizons



Bright and dark regions can be seen on Pluto, with astronomers detecting a possible polar cap

Additionally, it will also be a good opportunity to find out more about the aspects of Pluto astronomers are certain about. It is understood Pluto has low surface gravity, an estimated temperature of -233 degrees Celsius (-387 degrees Fahrenheit) and its atmospheric pressure is 100,000 times less than Earth's. "We know for a fact that Pluto's surface markings have moved and changed since the Nineties and we know for a fact that Pluto's atmospheric pressure has more than doubled since the Eighties, so we know that Pluto is dynamic; it's changing," says Dr Stern.

But Pluto's moons represent more of an unknown. When New Horizons was being planned, Charon was Pluto's only known moon. But, months before the mission launched, the Hubble Space Telescope (HST) suggested Pluto had two extra moons: Nix and Hydra. There were more to come too. In July 2011, HST found a fourth moon and, a year later, a fifth. They were called Kerberos and Styx.

"There is circumstantial evidence that there could be surface activity on the big moon, Charon. We see that because we have detected crystal and water ice there - and crystal and ice can't survive for long space," says Dr Stern. "The radiation in space changes the crystal structure so the fact that we see hexagonal crystals tells us that ice must be young. We also see, compositionally, a material on the surface of Charon called ammonia hydrate, which often is the result of cryovolcanism, a cold form of volcanism. Those are hints Charon may be active."

The discovery of the extra four moons changed the mission in two significant ways. Not only was the team able to schedule observations of them into the mission - "if we hadn't known about them we couldn't have done that" - they had to rethink the logistics of the flyby. "We realised these four satellites could present hazards, not because we are going to hit one but when there are craters, the shrapnel that comes out of the hole can get into orbit around Pluto

and be a danger," says Dr Stern. "So we put in place a seven-week search for hazards that New Horizons initiated in May, lasting all the way down until we are almost at Pluto. It will be searching to find out if the path that we plan to fly is safe or not. If it is not then we will fire the engines and move the spacecraft trajectory to a safer place."

A 93-second thruster burst has already adjusted the trajectory of New Horizons. It slowed the velocity of the spacecraft by 1.14 metres (3.7 feet) per second on 10 March and this shifted the course sideways by 3,442 kilometres (2,139 miles), pushing it towards the desired close-approach point of Pluto. But the moons continue to fascinate. On 18 February this year, New Horizons' Long-Range Reconnaissance Imager (LORRI) provided its first long-exposure views of Nix and Hydra at distances ranging from 201 million to 185 million kilometres (125 million to 115 million miles). By 13 May, it had brought Kerberos and Styx into view. Together with Charon, which had already been seen due to its size and greater brightness, it has meant all five moons have now been detected.

When the spacecraft gets close to the moons, it will seek to map their surfaces at a specified resolution and map their surface composition at another resolution. It will do the same when it nears

"We'll map the composition and obtain spectra at hundreds of thousands of locations on the disc"

**Dr Alan Stern**



Pluto itself. "We will map the surface geologies, the surface temperatures," says Dr Stern. "We'll map the composition, which means we will obtain spectra at literally hundreds of thousands of locations on the disc. We will map the surface topography because we will do stereo imaging so there are a whole variety of different maps that we will make.

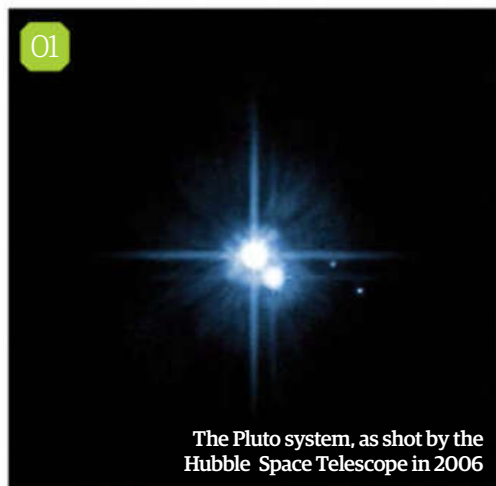
"By combining them - looking at the geology, the composition of the different types of features or whether there are thermal hotspots, for example - it can inform us what is going on in the planet, what's going on on the surface. It will tell us how Pluto has evolved and how it originally came to be."

At the same time, Dr Stern insists the spacecraft is not there to answer questions even though many can be posed. "We don't know what questions to ask," Dr Stern explains. "We are there to collect certain data sets that will allow us to explore the Pluto system. It's what the early space programme was about but done with 21st century technology."

More than 1,000 images are being sent to the ground team on its way to the encounter and while LORRI may be the least sophisticated instrument on the spacecraft, it will arguably produce some of the most exciting data. "It's got a big telescope in front of it so it's high magnification," says Dr Stern. "But it only has one charge-coupled device (CCD) and it's black and white, what we call panchromatic."

Those high-resolution images will be backed up by snaps taken from a digital imager called Ralph. Ralph will make the maps that show what Pluto, Charon and the Kuiper belt objects look like at light levels 1,000 times fainter than daylight at Earth. On 14 April this year, it took the first colour image. Eventually it will deliver images showing surface features as small as a few miles across. "It has eight CCDs, both colour and black and white, both scanning and framing cameras, and inside it also has an infrared mapping spectrometer with 64,000 pixels that is dramatically advanced compared to the Voyager devices of the same type," Dr Stern explains.

This will help to ensure that space enthusiasts and astronomers are glued to their TVs and the internet as more images and news filters through. "This mission is the capstone to the historic first era of reconnaissance, the equivalent of the summiting of Mount Everest," says Dr Stern. "It is just as significant as when the last of the continents of Earth were conquered... I can't be more proud of the team." ■



## Pluto: the missing pieces

There are many things we don't know about Pluto. We asked leading scientists what they hoped to learn



### **01** How Pluto fits in

**Dr Harold Weaver, New Horizons project scientist, The Johns Hopkins University Applied Physics Laboratory**

"I want to transform Pluto from a pixellated blob into a world with complexity and diversity. What does Pluto's landscape really look like? Are there high mountains and deep valleys? Are there cryovolcanic vents hinting at interior activity? And how do Pluto and its moons compare to other bodies in the Solar System?"



### **02** Pluto's actual size

**Dr Marc Buie, astronomer, Southwest Research Institute**

"The simplest thing I want to learn is the actual size of Pluto. However, I also really want to see how geologic and surface processes on Pluto relate to the known albedo patterns. Are they connected or are they independent?"



### **03** The atmospheric make-up

**Dr Randy Gladstone, institute scientist, Southwest Research Institute**

"I'm interested in how atmospheres work and what they are made of, so learning that (at long last) for Pluto is what I'm most looking forward to this summer. Pluto's atmosphere is likely very extended and rapidly escaping (because Pluto is small), with a lot of the same molecules found in Titan's atmosphere, but I still expect to be surprised."

**02**



**04**



05



### The surface composition 04

**Dr Cathy Olkin, principal scientist, Department of Space Studies at the Southwest Research Institute**

"I am interested in what the surface of Pluto is made of.

I have spent years studying Pluto through telescopes looking at the signatures of surface materials (mostly ices of different types: methane, nitrogen and carbon monoxide) on Pluto's surface. The close-up investigation of Pluto by New Horizons will allow us to map the surface composition of Pluto and that is something that I am very excited about."



### The solar wind interaction 05

**Prof Fran Bagenal, professor of astrophysical and planetary sciences at the University of Colorado, Boulder**

"How does Pluto's escaping atmosphere interact with the atmosphere escaping from the Sun - the solar wind? We expect to measure where the ionised component of Pluto's atmosphere holds off the solar wind and this will tell us how much material is escaping. Current estimates are about 1,000 truckloads a day!"



### The geologic processes 06

**Dr Jeffrey Moore, scientist, NASA Ames Research Center**

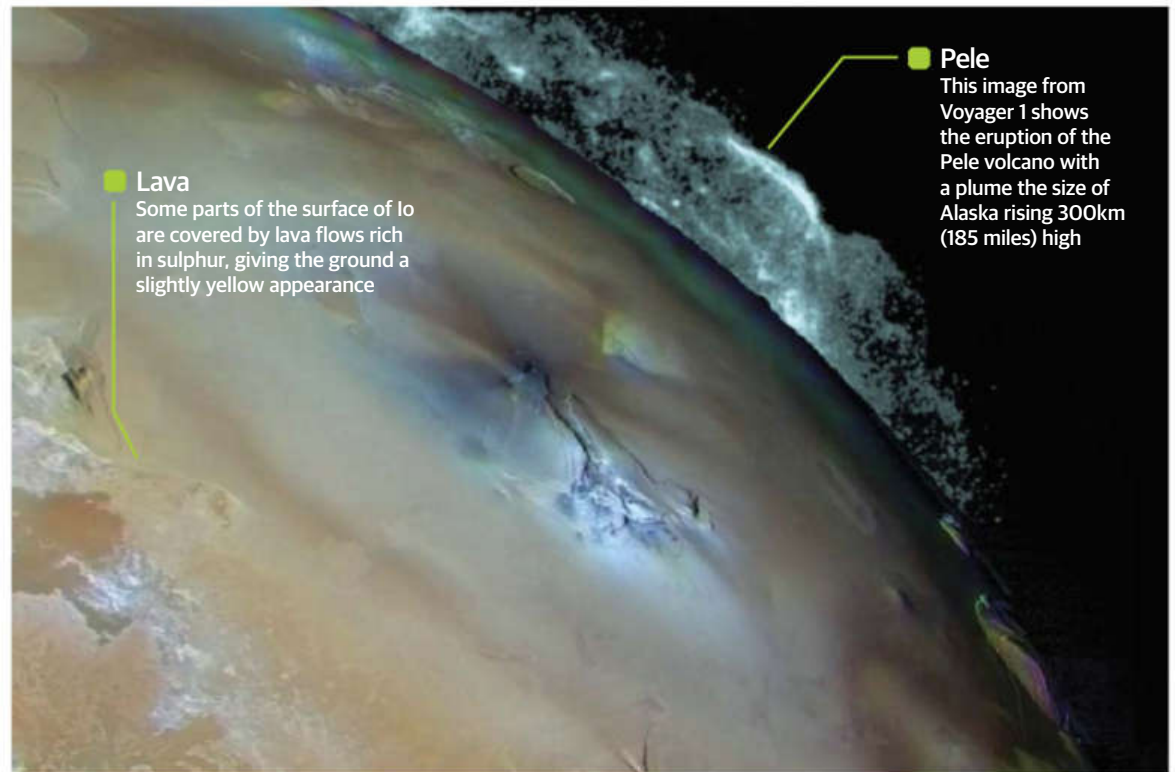
"I'm a geologist so I want to know what are the geologic processes that have shaped the surface of Pluto and its moon. It is important to understand which processes came first, and which ones are still acting on its surface. Maybe we'll see evidence for internal activity. Hopefully we can decipher the geological histories of Pluto and its moon."



# Alien volcanoes on Io

Exploding mountains and lakes of lava, why Io is the most exciting place in the Solar System





### Lava

Some parts of the surface of Io are covered by lava flows rich in sulphur, giving the ground a slightly yellow appearance

### Pele

This image from Voyager 1 shows the eruption of the Pele volcano with a plume the size of Alaska rising 300km (185 miles) high

In 1979, NASA's two Voyager spacecraft flew by Io, the fourth largest moon in the Solar System and the innermost of Jupiter's four main Galilean moons, and returned some startling information. While moons in the Solar System were once thought to be lifeless hunks of space rock, both spacecraft had directly observed volcanic features on Io. Bearing more resemblance to a pepperoni pizza than a giant moon, it was apparent that Io was one of the most fascinating and significant objects in our Solar System.

Our own Moon is one that appears to have been active in the past but has quietened down to become almost entirely dormant, retaining little to none of the volcanic activity that once sculpted its surface. Indeed only a few planets, Earth included, have changeable environments at all, making the discovery of Io all the more exciting. Where once our Solar System was regarded as an ever-present museum of the past, moons such as this one have proven that it is still a lively and effervescent place. So what is it that makes Io so amazing?

To date, Io has more than 400 known active volcanoes, making it the most volcanically active object in the Solar System, even more so than Earth. Dozens of vents are strewn across its surface leaking gas into the atmosphere, while at its poles and even occasionally close to the moon's equator vast icy plains can be found. The remnants of Io's volcanic past



Volcanic plumes on Io can tower 300km (190 miles) in height and reach half the speed that would be needed to escape the gravity of the moon

and present are as clear as day, with large volcanic rings the size of California encircling either dormant or active volcanoes.

While data from the Voyager probes, and later the Galileo spacecraft, has shown us volcanic plumes erupting from the surface of the moon, we are also able to discern some of Io's erupting monsters from observations on Earth. Some volcanoes have even been active for over two decades, meaning that the driving force below Io's surface is even more violent and ferocious than once thought.

The reason for Io's outbursts of activity is that it is being battered

and bruised by Jupiter and its other moons. Io sits at a distance of 420,000 kilometres (260,000 miles) from Jupiter, which might sound quite far away but consider that our own Moon sits 385,000 kilometres (240,000 miles) away from us and that Jupiter is almost 318 times more massive than Earth, while Io is almost exactly the same size as our Moon. For this reason it's obvious that while the Earth exerts a small but noticeable force on the Moon, causing it to become gravitationally locked to our planet only a billion or so years ago, Jupiter is exerting a huge force on Io. This moon, which itself is gravitationally locked to



Jupiter, is being constantly pushed and pulled by the huge gas giant, which in turn is churning its insides. Add into this that the other three Galilean moons, of which Io is the second smallest but the closest to Jupiter, also exert a gravitational influence on the poor moon, and you might start feeling sorry for this troubled space rock. The influence of the other moons means that Io's orbit around Jupiter is eccentric, with a difference of 3,400 kilometres (2,100 miles) between its closest and furthest points. So, even though the same face always points towards Jupiter, Io experiences huge changes in gravitational force from this big bully of a planet.

In fact, the force on Io is so intense that its solid surface acts in a similar manner to oceans on Earth. It bulges up and down by as much as 100 metres (330 feet) in places, compared to 18 metres (60 feet) for the highest tides on Earth. Bear in mind that Io's tides are made of solid rock and those on Earth are made of water, and you might realise just how tough a time this moon is having.

These tidal forces create a huge amount of heat in Io's interior, and therefore the majority of its subsurface crust is a liquid. This liquid is under intense pressure and looks for any escape route possible out onto Io's surface, be it in the form of a volcano, geyser or vent. This makes the surface a constantly changing place, with plumes of sulphur dioxide snow ejecting all over it. Any meteorites that hit the moon instantly see their impact craters filled with lakes of molten lava from the interior. The composition of this lava is still somewhat of a mystery but the two main theories suggest that it is either made from various compounds of molten sulphur or silicate rock. The former would account for the odd colouring of the moon, while the latter would better explain the hot temperatures under the surface where it may be too hot for sulphur to exist.

As more missions are sent to the Jupiter system we will learn more about this fascinating and mysterious moon. NASA's solar-powered spacecraft Juno, which launched in August 2011, will enter orbit around the largest planet in our Solar System in July 2016. This will be followed by the ESA's Jupiter Icy Moon Explorer, which is set to launch in 2022 and arrive at Jupiter in 2030. ■

## Tidal flexing on Io

**Europa**  
Io's orbit is not circular due to the gravity of neighbouring moons Europa and Ganymede

**Elliptical**  
Because of its elliptical orbit, Io is stretched and twisted over regular time periods

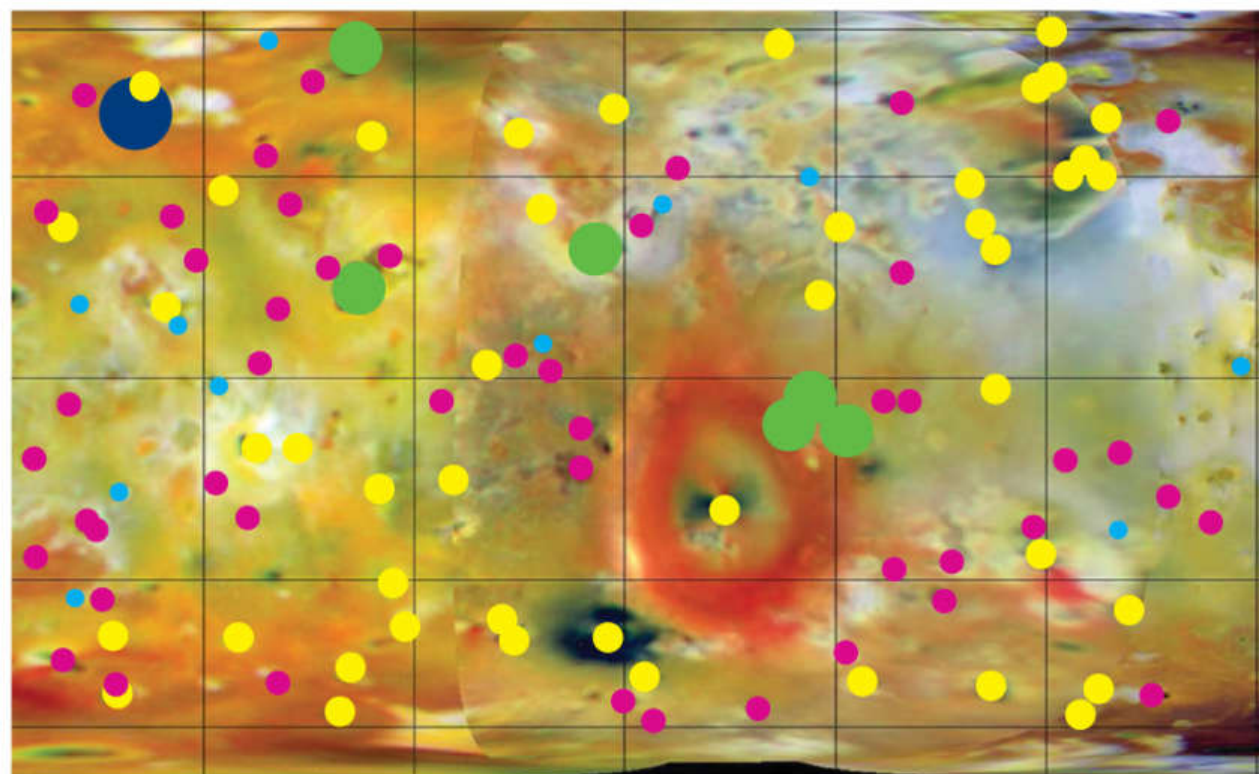
**Heat**  
The tidal flexing heats Io's interior in the same way a paperclip warms when you bend it. The heat escapes through powerful eruptions

**Stretched**  
Io experiences more tidal stretching from its host planet than our own Moon due to Jupiter's massive size

## Biggest volcanoes on Io

The strength of volcanoes on Io is measured using the gigawatt, a unit of power equal to a billion watts. For comparison, ten gigawatts is approximately equal to the power the Space Shuttle produced at lift-off

● >10,000 GW (gigawatts) ● 1,001-10,000 GW ● 101-1,000 GW ● 11-100 GW ● 1-10 GW





## Alien volcanoes on Io

### Mantle

The mantle of Io is thought to be made of a magnesium-rich mineral called forsterite, while up to 20% of it may be molten

### Temperature

The surface temperature on Io ranges from  $-180^{\circ}\text{C}$  ( $-290^{\circ}\text{F}$ ) to  $-140^{\circ}\text{C}$  ( $-220^{\circ}\text{F}$ )

### Size

Io is slightly larger than our own Moon with a diameter of about 3,600km (2,240 miles)

### Core

Measurements made by the Voyager and Galileo spacecraft suggest that at Io's centre is an iron-rich core

### Lithosphere

The upper portion of the mantle, the lithosphere, is made of basalt and sulphur deposited from the various volcanoes on Io

## Io's other amazing features

### Freezing cold

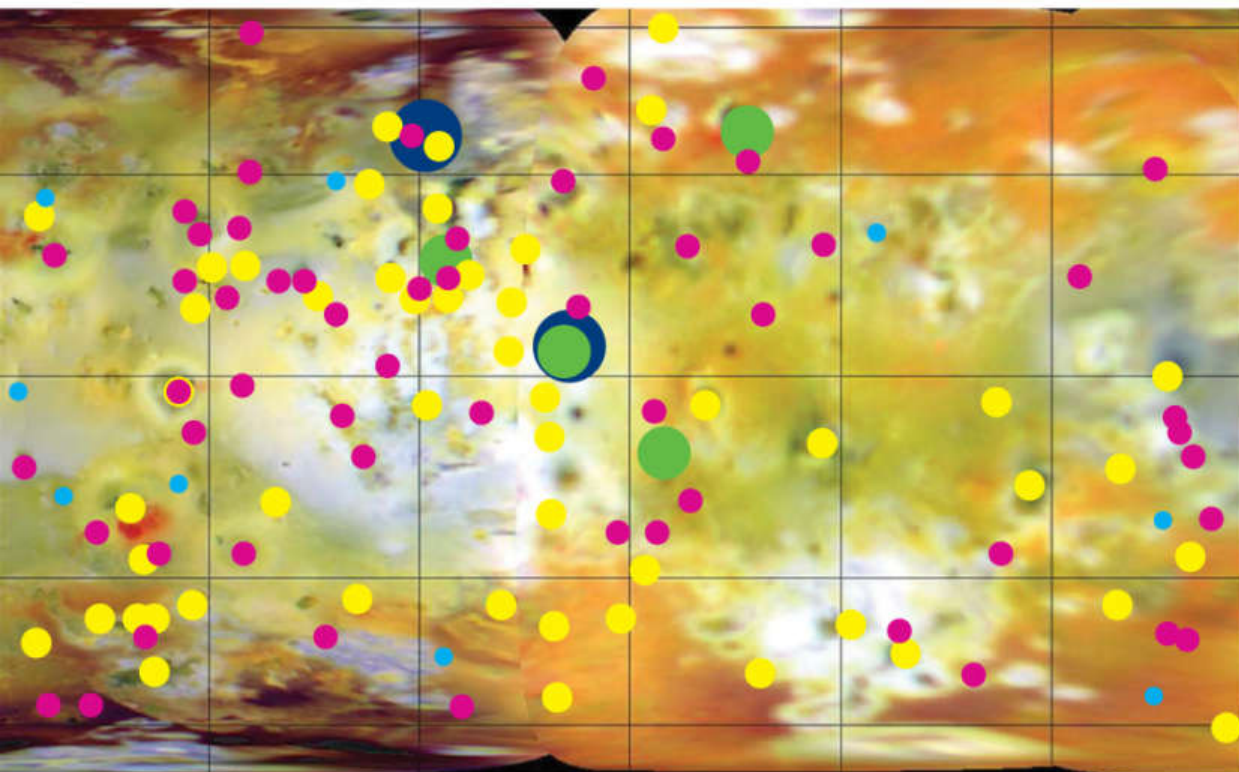
One of the most astounding things about Io is that, despite the number of active volcanoes on its surface, it has a maximum surface temperature of  $-140^{\circ}\text{C}$  ( $-220^{\circ}\text{F}$ ). This is because Io's atmosphere is incredibly thin, with volcanic gases instantly freezing and condensing upon eruption rather than adding to the atmosphere like on Earth.

### Lightning storms

Io's orbit sees it cut across Jupiter's magnetic field lines, turning the moon into a giant electric generator. In fact, Io generates about 400,000 volts across itself, in turn creating 3 million amperes of current. This makes its way back along Jupiter's magnetic field lines and causes lightning storms in its upper atmosphere.

### Magnetic field

The magnetic field of Jupiter also has another effect on Io. As it sweeps past the moon it actually strips off about 1,000kg (2,200lb) of material per second, which in turn becomes ionised and forms a ring-shaped cloud of radiation. The ions in this ring create auroras at the planet's poles, and also inflate Jupiter's magnetosphere to twice its expected size.





# Sights of the Universe

From what stars are made of to our relationship with space

## **102** Mega storms

Find out about the deadly weather of space

## **112** What happens inside a star?

Learn about the processes inside the stars

## **114** How planets form

Discover how our planet came into being

## **120** What are asteroids made of?

Explore the physical properties of space-rocks

## **124** 5 facts about moondust

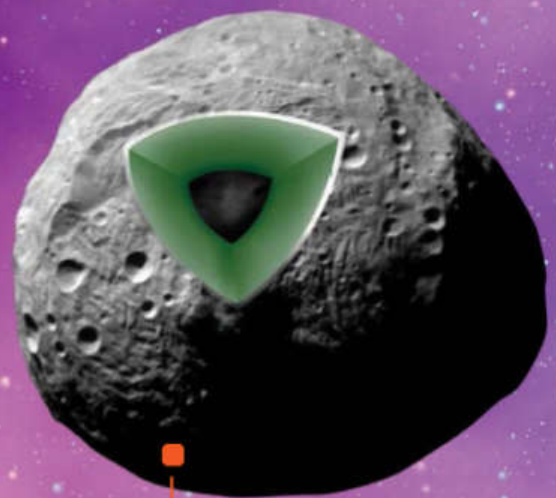
Find out about the scientific value of this material

## **126** Deadly space junk

Space debris waiting to cause disaster



**112**  
Inside a  
star



**120**  
Asteroid  
make-up



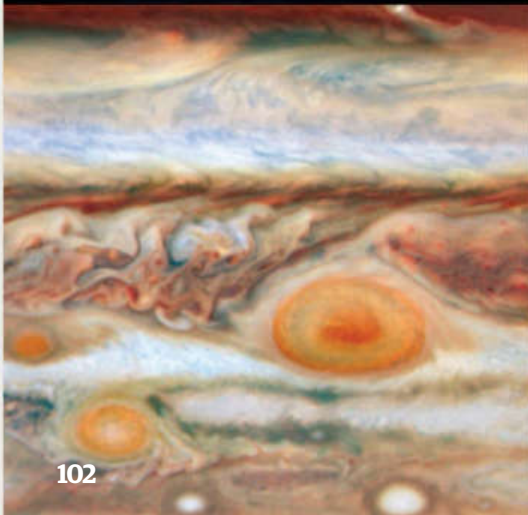
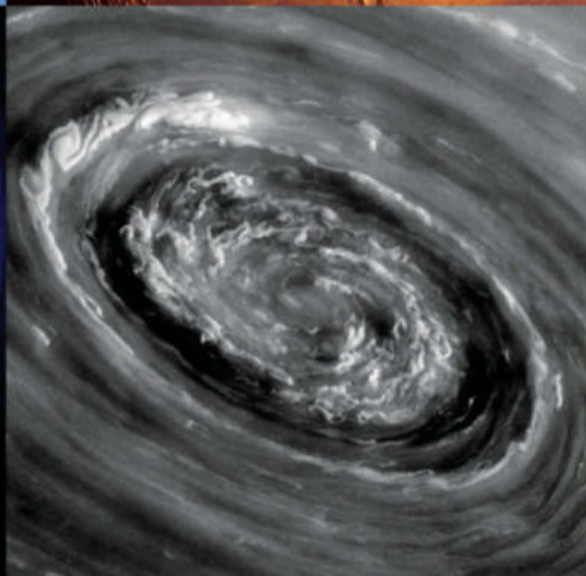
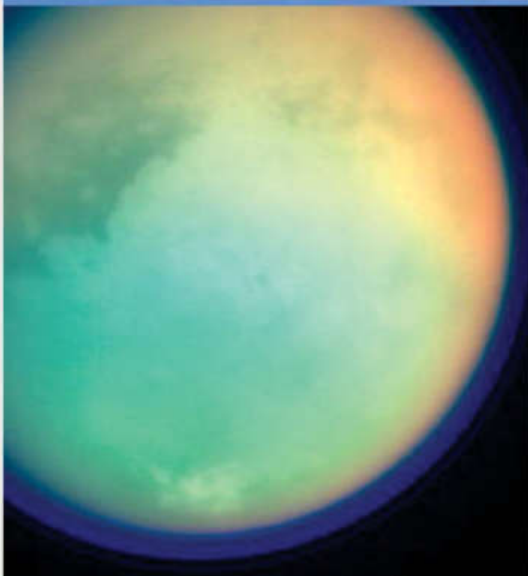
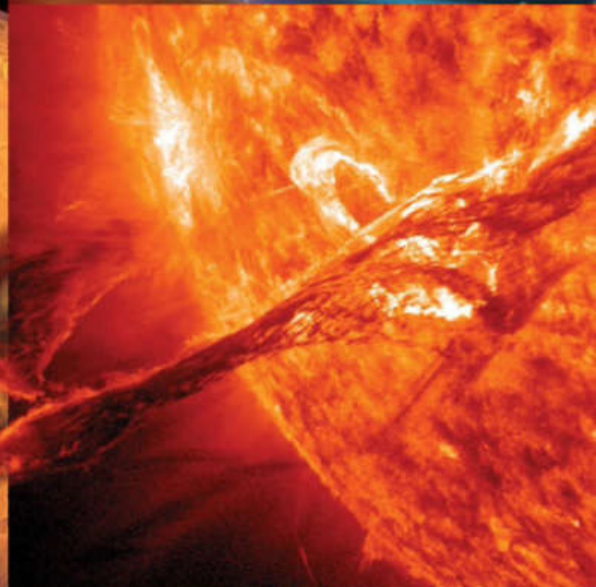
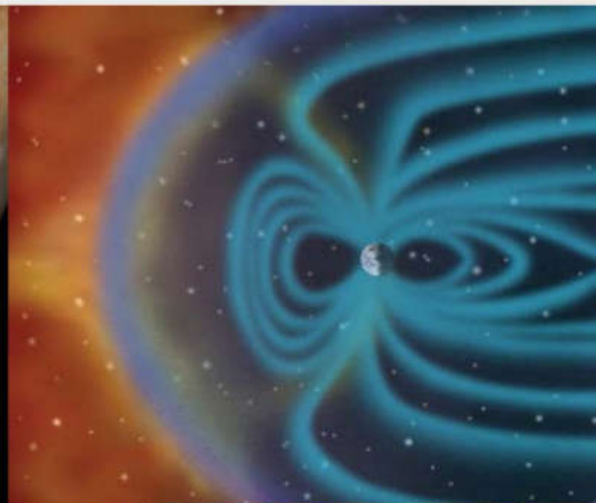
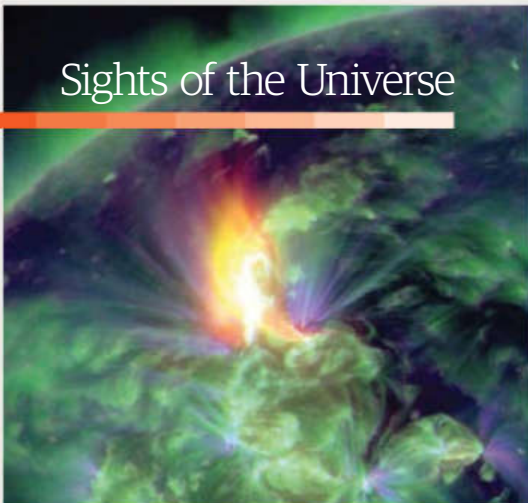


**114**  
Planet  
formation

**124**  
Moondust

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Mega  
storms









Deadly weather in space

# DEADLY WEATHER IN SPACE

# MEGA

# STORMS

From solar flares that knock out satellites to 1,500mph hurricanes on the surface of alien worlds, we explore some of the most extreme weather in the Solar System





# Our angry, stormy Sun

We know our Sun as a brilliantly bright sphere that rises in the east and sets in the west each day. That's a simple way to describe it; what really goes on on its surface is far from the impression that it gives as it hangs, almost calmly, in the daytime sky.

While going anywhere near the Sun would be suicide with the searing heat and penetrating radiation combining to fry you alive in your spacesuit, technology has revealed this star to be an angry, bubbling cauldron of solar activity.

First up are solar flares - bursts of radiation from the sudden release of magnetic energy from active regions on the Sun's surface, the photosphere. These regions are centred on sunspots, which are tangled knots of magnetic fields. The flares release as much as a sixth of the total amount of energy that the Sun releases every second, with much of it in X-rays or ultraviolet light. The energy of a flare can drive a cloud of charged particles to escape the solar corona in a coronal mass ejection (CME). The CME becomes a giant cloud of plasma hurtling through space and, when CMEs are pointed towards Earth, they cause solar storms.

When a CME strikes the Earth's magnetosphere, it overloads the system and becomes a geomagnetic storm. Earth's magnetosphere is compressed to breaking point with charged particles flooding the magnetic field lines that loop down on to the magnetic poles of the planet. The particles excite atmospheric gases (mainly oxygen and nitrogen), causing them to glow in eerie shimmering curtains of light - the aurora borealis (northern lights) and the aurora australis (southern lights). Oxygen gas glows green, while nitrogen glows purplish-red - the two primary colours seen in auroras. Usually low-level solar wind activity means that the 'auroral arc' is kept, in the northern hemisphere, to the Arctic Circle but the power of a geomagnetic storm can see the auroral arc extend to more southerly latitudes, over Britain and Western Europe, as far south as Spain or even, on very rare occasions, Florida in the United States. The most severe solar storm on record was the Carrington event of 1859, when auroras lit up the skies as far south as the tropics

and telegraph wires began to short, sparking electricity.

Those telegraph wires remind us that auroras are only the pretty side of a geomagnetic storm. Although they are not directly harmful to people on the ground, a storm instigated by a powerful CME can destroy our technology. Satellites can short-circuit, knocking out communications. Astronauts must take shelter from the radiation in a special, shielded

room onboard the International Space Station. On the ground, power lines can become swamped by raw current from the CME plasma - in 1989, a solar storm caused a large, nine-hour blackout in Quebec in Canada. In our modern world, where we rely on electronic devices, the nightmare scenario is that a powerful enough solar storm could stop everything working, wiping computers, crashing the internet, knocking out global

## Solar wind current

### 1. Surface of the Sun

The Sun's magnetic field is very complex on the solar surface, but as it rises into the corona it simplifies until it consists of two opposite polarities separated by the line of the heliospheric current sheet.

### 2. Corona

In the corona the solar wind begins to draw out the heliospheric current sheet into space, extending the

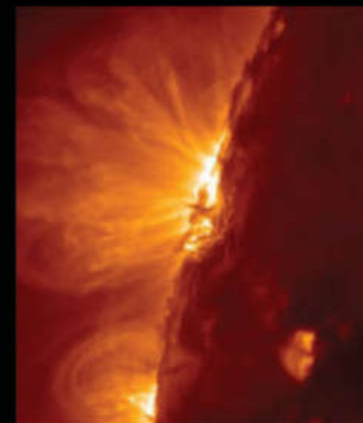
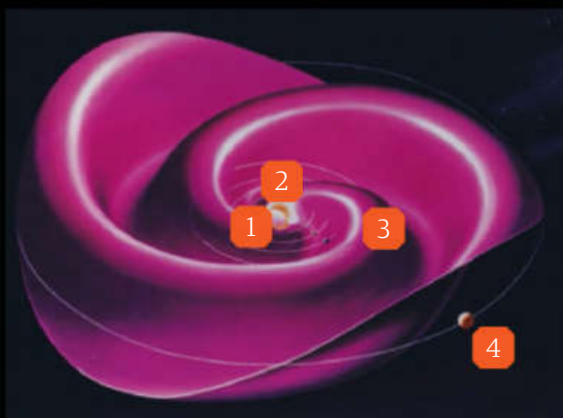
Sun's atmosphere out into the rest of the Solar System.

### 3. Rotation

As the Sun rotates, it causes the heliospheric current sheet to become twisted.

### 4. Jupiter

It takes material in the heliospheric current sheet three weeks to reach Jupiter. The sheet eventually extends out into the Kuiper belt, where the Voyager spacecraft are exploring.



A solar prominence is an eruption of hydrogen gas from the Sun's surface

## WHERE DOES THIS HAPPEN?





# Solar winds that batter Earth

## Mega Storms

### The solar wind

The solar wind blows through holes in the Sun's outer atmosphere, known as the corona. The wind itself consists of energetic charged particles

### Magnetopause

This is where the force of the solar wind balances with the strength of the magnetosphere and exists up to several hundred kilometres from Earth's surface

### Magnetosphere

The Earth's magnetic envelope, generated by our planet's internal dynamo, protects Earth from the solar wind

### Auroras

Charged particles follow magnetic field lines down to the poles where they excite molecules in the atmosphere, causing them to glow as the northern and southern lights

### Magnetotail

The pressure of the solar wind sculpts Earth's magnetosphere, compressing it on the Sun-facing side and stretching it out into a tail shape on the opposite side

### Magnetic reconnection

When magnetic field lines break and reconnect in the magnetopause, it allows solar wind particles to sneak through

## "A powerful enough solar storm could wipe computers, crash the internet and knock out global power systems"

power systems and disrupting communications. It may take months to get everything back online, in which time the world has been sent into technological, social and economic chaos.

We're most vulnerable to solar storms at solar maximum, which is the point in the Sun's 11-year cycle of activity when our nearest star is at its most active. Solar flares happen all the time, and CMEs strike Earth

frequently, but only rarely are they as powerful as the solar activity that plunged Quebec into darkness. However, scientists are currently unable to predict solar activity or when the next big CME will be.

All of this takes place in the Sun's heliosphere, which is the extent of its magnetic influence throughout the Solar System, where the solar wind still blows. The heliosphere goes out past the orbit of Pluto. The

Voyager 1 spacecraft is currently 118 times further from the Sun than Earth is, and yet it has still to leave the heliosphere. CMEs disperse and lose power the deeper they get into the Solar System. However, solar activity can still have an effect, even on the edge of the heliosphere. Both Voyager 1 and 2 have experienced the heliosphere swelling and shrinking on gusts of the solar wind that inflate the Solar System's magnetic bubble. ●



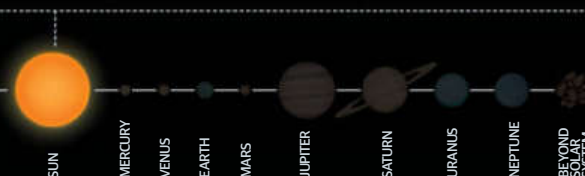
## The solar maximum

Roughly every 11 years, the Sun goes through a natural cycle marked by an increase or decrease in dark blemishes on the Sun's surface, or photosphere, known as sunspots. We refer to the multiplication of sunspots as the solar maximum and the smaller number the solar minimum.

During the solar maximum things get exciting; bright luminous regions also appear in the Sun's atmosphere, called the corona, and it is here where our Sun has an angry outburst; fiercely spitting charged particles and magnetic fields from its surface in a gigantic burst of a supersonic solar wind, called a coronal mass ejection.



The aurora borealis (northern lights) and aurora australis (southern lights) can be seen in the northern and southern hemispheres of our planet





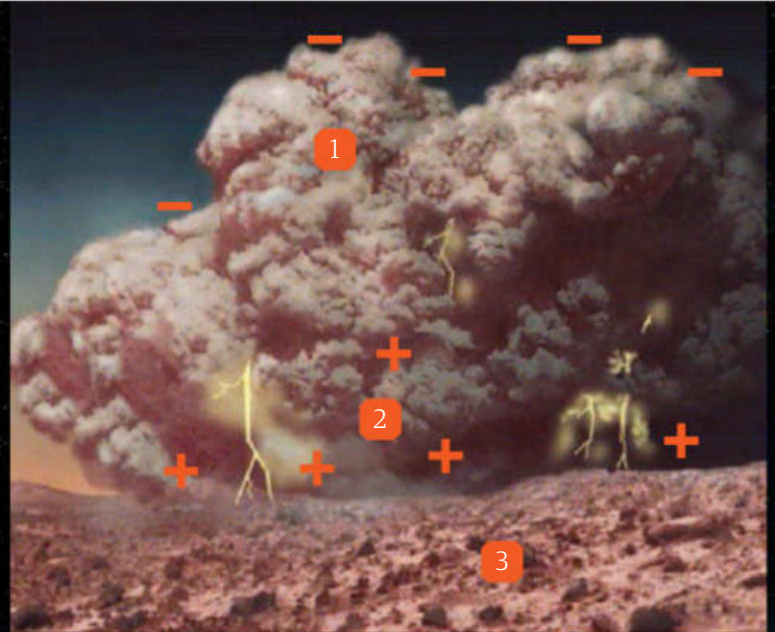
# Dust storms that cover the planet

Now this is really bad weather – a dust storm that doesn't just cover an area, or even a hemisphere, but the entire planet. During summer in the Red Planet's southern hemisphere, when Mars is at its closest point to the Sun, solar heating can drive immense storms that blow up red dust and can obscure the surface for months. In 1971, when Mariner 9 arrived at Mars, it found the whole planet hidden under a veil of dust, with only the volcano Olympus Mons visible. More recently, the Mars Exploration Rovers Spirit and Opportunity would struggle to survive in dust storms as the Sun's light was blocked and their solar panels covered by a coating of dust.

On Earth, moisture arms swirling storms, but on Mars there is only dust. Normally most of the dust is on the ground, but some is found in the atmosphere, where it scatters sunlight and makes the sky appear pinky-red. When Mars is at its hottest – still cold enough to freeze water –

the atmospheric dust can absorb the energy of the sunlight, which causes warm pockets of air to rapidly move towards colder, low-pressure regions, generating winds up to 45 metres per second (162 kilometres per hour or 100 miles per hour) that begin to pick up dust particles from the ground, adding to the atmospheric dust content and increasing heating, pushing the winds harder and faster until the atmosphere is filled by dust.

And then, just as quickly, the storm can die down. Perhaps by blocking the sunlight, the surface of Mars grows cooler, allowing some of the dust to begin sinking out of the atmosphere. Not all dust storms swallow the entire planet – some are more localised events. However, were you to be on the surface during a dust storm, other than the sky darkening and a fine coating of dust settling over you, the atmosphere is so thin that you'd barely notice the wind or the scouring dust. ●



## Kicking up dust

### 1. Desert dust

The dust storms, that frequently rise from the cold deserts of Mars, sometimes rage across the entire Martian globe, which crackle and snap with electricity.

### 2. Electrifying dust

It is possible that dust particles could be electrified in Martian dust storms when they rub against each other as they are carried by the winds, transferring positive (+) and negative (-) electric charges similar to the way that static

electricity can be built up from shuffling across a carpet.

### 3. Strong swirls

Electric fields generated by the swirling dust are thought to be strong enough to break apart carbon dioxide and water molecules in the Martian atmosphere recombining to make reactive chemicals like hydrogen peroxide, which you'll find in bleach or other cleaning agents, and ozone. Some of these reactive chemicals are likely to have accumulated in the Martian soil over time.

Snaking its way across Mars's surface, this dust devil is powered by solar heating just like the dust plumes found on Earth



## How do dust storms form?

### 1. Heating up the atmosphere

The absence of clouds or water means that radiation cannot be reflected back into space and the thin atmosphere close to Mars's surface becomes hotter than the atmosphere above it

### 3. The storm begins

The change in temperature creates winds, swirling at great speeds of 96 to 193km/h (60 to 120mph), capable of dominating the entire planet

Wind direction

### 2. Picking up the dust

As the atmosphere is heated dust is lifted into the air and, after absorbing more sunlight, the dust warms up the atmosphere further, propelling more dust into the air

### 4. Dusty dirt devils

As well as the gigantic dust storms, Mars's surface is also raked with frequent, and strong, dust devils

WHERE DOES THIS HAPPEN?





# Hurricanes bigger than Earth

Easily one of the most famous storms in the Solar System, Jupiter's Great Red Spot is so large that it is visible through many Earth-based telescopes.

The Great Red Spot is thought to have been in existence for at least 340 years. The oval red eye rotates in an anticlockwise direction due to the crushing high pressure on the planet. Winds can reach over 400 kilometres per hour (250 miles per hour) around the spot, however, inside the storm they seem to be nearly nonexistent. And that's not all, this complicated weather system has an average temperature of about -162 degrees Celsius (-260 degrees Fahrenheit).

At around eight kilometres (five miles) above the surrounding clouds and held in place by an eastward jet

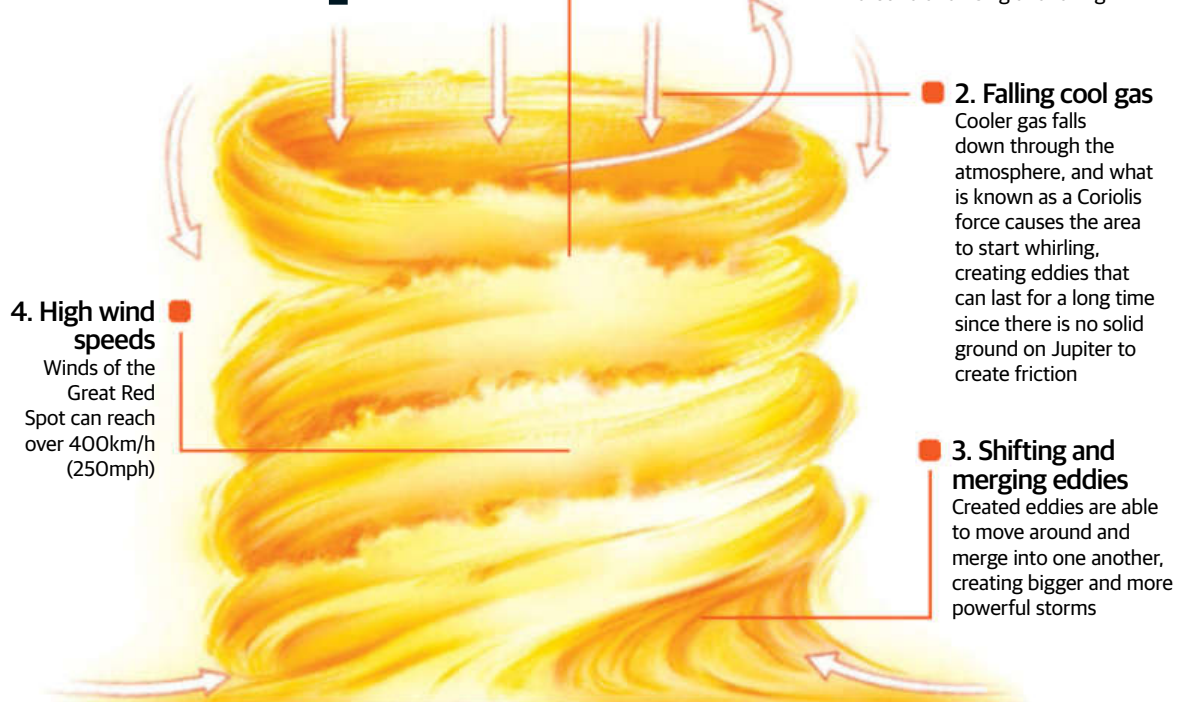
stream to its south and a very strong westward jet flowing into its north, the Great Red Spot has travelled several times around Jupiter, but how did such a behemoth of a storm come to appear on the gas giant's surface?

The answer is not clear at this time despite the efforts of planetary scientists attempting to unravel the answers. However, what experts do theorise is that the storm is driven by an internal heat source, and it absorbs smaller storms that fall into its path, passing over them and swallowing them whole. Another thing that they also know is that the Great Red Spot hasn't always been its current diameter. In 2004, astronomers noticed that the great storm had around half the 40,000-kilometre

(25,000-mile) diameter that it had around 100 years before. If the Great Red Spot continues to downsize at this rate, it could eventually morph from an oval shape into a more circular storm by 2040. You might think that this well-known feature won't be sticking around for long as it becomes smaller, but experts believe that the great age-old storm is here to stay since it is strongly powered by numerous other phenomena in the atmosphere around it.

Storms like these are not out of place on Jupiter, whose atmosphere is a zigzag pattern of 12 jet streams, with blemishes of warmer brown and cooler white ovals in the atmosphere owed to storms as young as a few hours or stretching into centuries.

## The science of the Great Red Spot



The white oval storm directly below Jupiter's Great Red Spot is about the diameter of Earth



It is thought that, between Jupiter's core and the cloud tops lies an ocean of liquid hydrogen

Interactions with other storms could give the Great Red Spot its monstrous energy





# The violent polar vortex

On the outside, Saturn almost looks like a calm, bland world, but once in a while, huge storms flare up on the ringed planet. From the short-lived Great White Spot of 1990, to the more recent storm of 2010, which grew into an atmospheric belt covering around 4 billion square kilometres (1.5 billion square miles), Saturn has proven to be a turbulent world. And what's more, the storms on Saturn are the second fastest in the Solar System, after ice giant Neptune, peaking at an impressive 1,800 kilometres per hour (1,120 miles per hour) and blowing in an easterly direction.

Temperatures on Saturn are normally around -185 degrees Celsius (-300 degrees Fahrenheit), but near the giant swirling polar vortex - a persistent cyclone taking pride of place at the ringed planet's south pole - temperatures start to warm up, and while the climate doesn't reach high enough for a suntan, this -122 degrees Celsius (-188 degrees Fahrenheit) vortex is the warmest spot on Saturn, with a powerful jet stream smashing its way through this terrifyingly fierce feature.

Saturn's north pole also has a giant storm of its own surrounded by a persistent hexagonal cloud pattern. Spotted in 1980 and 1981 during the Voyager 1 and Voyager 2 flybys, Saturn's hexagon, complete with six clear and fairly straight sides, is estimated to have a diameter wider than two Earths. The entire structure rotates almost every 11 hours.

Sighted much more closely by NASA's Cassini spacecraft in 2009 as springtime fell on the ringed giant's northern hemisphere, experts believe that the storm could have been raging for at least 30 years, whipping around at over 480 kilometres per hour (300 miles per hour) in a counterclockwise direction and disturbing frothy white clouds in its wake.

**Counterclockwise swirl**  
This storm angrily swirls in an anticlockwise direction rotating with a period of nearly 11 hours

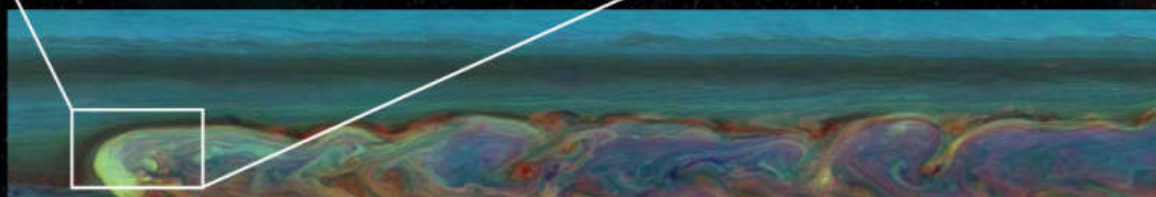
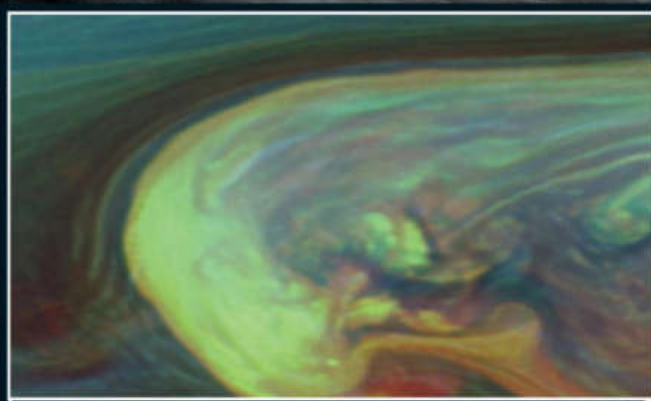
**Monstrous size**  
Not only is this storm violent, it is also argued to be an estimated 4,000km (2,500 miles) wide - roughly the distance between New York and Los Angeles!

**Rolling cloud formation**  
The bubbling of frothy clouds sit at the centre of Saturn's famed northern vortex, a hexagonal-shaped feature permanently characteristic of the planet's two poles

2,500 MILES

**Fast and furious**  
This swirling vortex, located above Saturn's north pole at the centre of a jet stream, whips around at a speed of 480km/h (300mph) and is believed to be at least 30 years old

Around once every Saturn year (roughly 30 Earth years), huge, turbulent storms work their way through the clouds of the northern hemisphere. The storm pictured here, which was imaged in 2011, is the longest storm to date lasting roughly 200 days



## WHERE DOES THIS HAPPEN?





# Deadly methane rain

With a surface pressure almost one and a half times that of Earth's, Titan's atmosphere is slightly more massive than our planet's overall, taking on an almost chokingly opaque haze of orange layers that block out any light that tries to penetrate the Saturnian moon's thick cover.

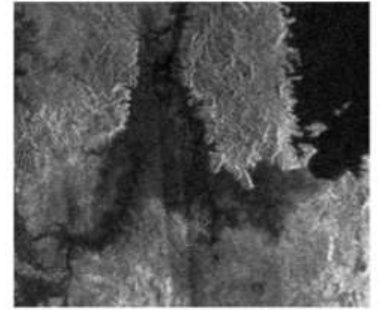
Titan is the only other world, other than Earth, where liquid rains on a solid surface. However, rather than the water that we are used to falling from the skies above us, pooling into puddles and flowing as streams and rivers, this moon's rains fall as liquid

methane - liquid hydrocarbons that add more fluid to the many lakes and oceans that already cover the surface. And it is thanks to the moon's complex methane cycle, similar to the natural processes found on Earth, that this is possible.

Rain falls quite frequently on Earth, however, the same can't be said for some regions on Titan. Springtime brings rain clouds and showers to Titan's desert with the moon

only experiencing rainfall around once every 1,000 years on its arid equator. However, these rain showers certainly make up for the lack of activity by dumping tens of centimetres or even metres of methane rain on to the Titanian surface.

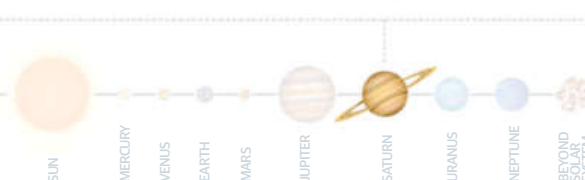
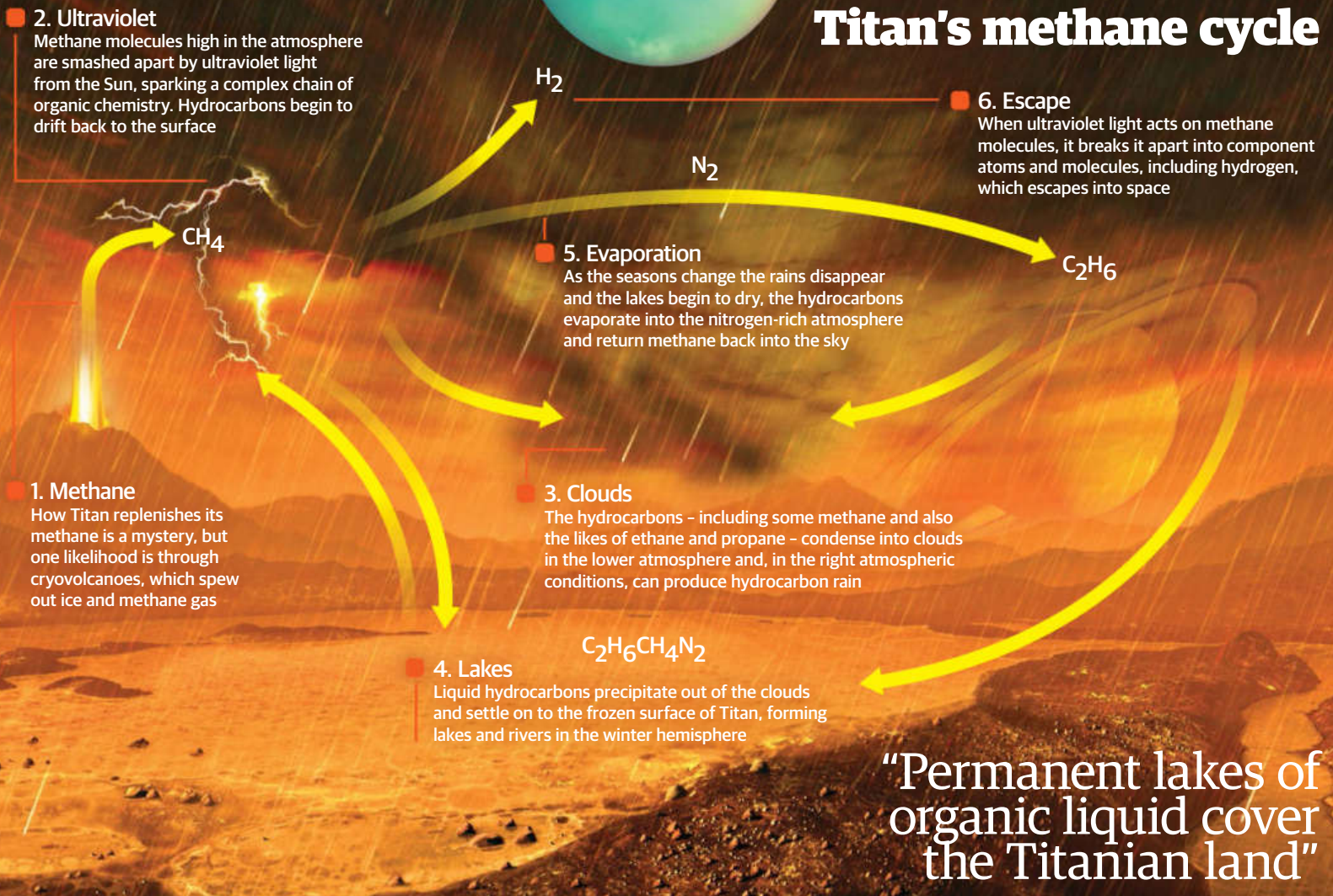
At the poles of the moon its a completely different story, however. Methane rain falls much more frequently, replenishing the lakes of organic liquid covering the Titanian land. ●



Titan's lakes and rivers of liquid hydrocarbon are thought to be fed by methane rains brought about by the moon's complex methane cycle



## Titan's methane cycle





# Winds at twice the speed of sound

We've all got stuck out in or witnessed very strong winds here on Earth, from gusts that turn your umbrella inside out to tornadoes that rip up everything in their path. You might think these winds are a force to be reckoned with, but unless you've had a day floating around the gaseous atmosphere of ice giant Neptune you haven't seen anything yet!

You might think that Neptune's distance from the Sun, which creates temperatures as low as -218 degrees Celsius (-360 degrees Fahrenheit), would mean a world frozen solid by the subzero climate with not much going on in terms of weather. However, you would be incorrect. The winds that race through its hydrogen, helium and ammonia-laden atmosphere can

reach maximum speeds of around 2,400 kilometres per hour (1,500 miles per hour), making this dark horse probably the most violently stormy world in the Solar System, and making our most powerful winds look like light breezes.

Neptune's fastest storms take the form of dark spots, such as the anticyclonic Great Dark Spot in the planet's southern hemisphere and the Small Dark Spot further south - thought to be vortex structures due to their stable features that can persist for several months - as well as the white cloud group, Scooter.

So what causes these winds?

Neptune might be extremely frosty, but astronomers think that the freezing temperatures might be responsible; decreasing friction in the gas giant to the point where there's no stopping those super-fast winds once they get going.

Delving into its layers of gas, we find another possibility pointing to just how these active storms came about as the temperature starts to rise. As things get more snug closer to the centre, the internal energy could be just what is driving the most violent storms that we've ever witnessed. ■

## "The most violently stormy world in the Solar System"

Long bright clouds on Neptune's surface are similar to cirrus clouds on Earth



The gas giant's atmosphere as imaged by the Voyager 2 spacecraft in 1989

## Neptune's atmosphere

### A stormy surface

Storms reaching speeds up to 2,400km/h (1,500mph), are thought to continually rage on the surface of Neptune and make their presence known in the form of blemishes on the otherwise featureless surface

### Great Dark Spot

This anticyclonic storm, which was seen to be morphing into different shapes and sizes, was found to have disappeared by 1994 and was later replaced by a similar feature in the planet's northern hemisphere called the Northern Great Dark Spot

### Clouds and storms

The cyclonic storms, which are thought to be holes in the upper cloud decks of Neptune, are thought to occur in the troposphere at low altitudes compared to the brighter white clouds

### Small Dark Spot

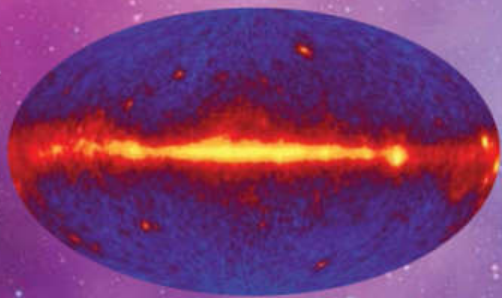
This storm, also called The Wizard's Eye, was measured to be the second most violent storm on Neptune. Just like the Great Dark Spot, the Hubble Space Telescope found that this cyclone had disappeared in 1994

WHERE DOES THIS HAPPEN?



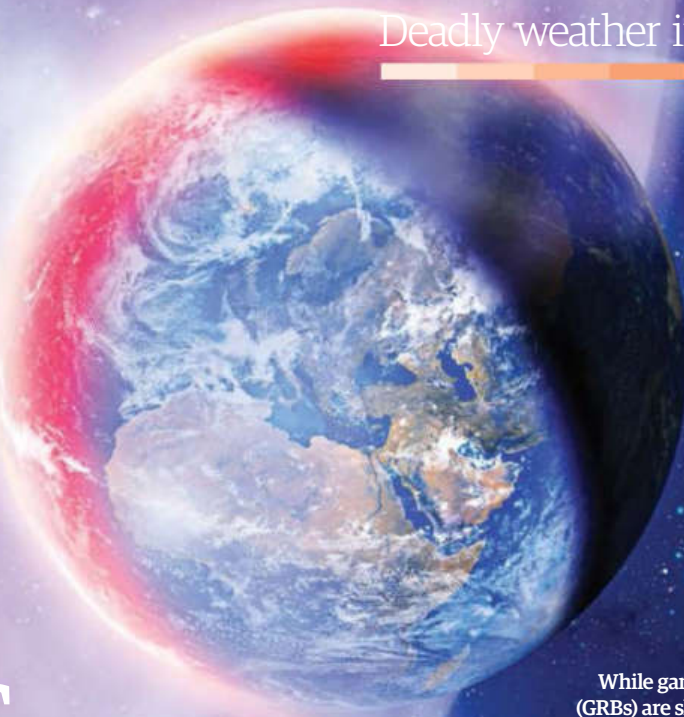


An all sky gamma ray map taken by the Compton Gamma Ray Observatory (CGRO)



# Deep space: Lethal gamma rays

Deadly weather in space



While gamma-ray bursts (GRBs) are short-lived, they can pack a punch of energy hundreds of times brighter than your standard supernova

Releasing more energy in a mere ten seconds than the Sun will during its entire 10 billion-year lifetime, gamma-ray bursts reign supreme as the most deadly source of radiation known to man, pipping X-rays to the post.

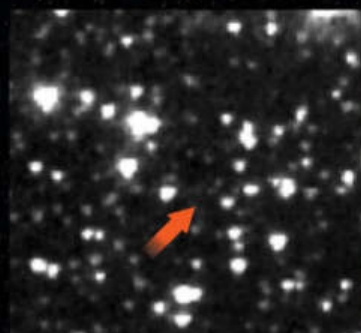
Taking a trip just outside of the Earth's atmosphere, you'll find that gamma rays are everywhere, however, one of the greatest difficulties in detecting gamma-ray bursts is their incredibly short life span, lasting from just a fraction of a second to over 1,000 seconds. While they can't be seen by our visible light-sensitive eyes, space observatories such as NASA's Fermi Gamma-ray Space Telescope, which is currently performing observations from low Earth orbit, paints a picture of a gamma ray cosmos, proving just how exotic and fascinating our universe is.

But such a high level of radiation doesn't just come out of nowhere, there are many phenomena occurring deep in space, spilling out gamma rays from every pore of the hottest regions of the universe. These hot regions produced in the hearts of solar flares, the explosion of supernovas, neutron stars, black holes and active galaxies, provide these sources.

Back here on Earth we are protected from these bursts of gamma rays by our planet's atmosphere as, unless you're wearing a suit of lead,

any interaction with this ionising radiation could prove disastrous as they penetrate through the human body destroying every cell in its path.

But what would happen to life on Earth if we happened to be in the firing line of some intense gamma ray spewing from phenomena such as the nearby explosion of supernovas, an off-the-scale burst from a solar flare destroying the ozone layer, or perhaps the collision between two nearby neutron stars? The answer is not a pleasant one as exposing life as fragile as ours to such a harsh environment would quickly change our currently perfectly balanced world into a deadly orb setting in motion a mass extinction, picking off and destroying life as we know it. ■



**Gamma-ray bursts (GRBs) are gigantic blasts of light whose afterglows fade incredibly fast, lasting anywhere from just a few hours to a few days**

## Gamma ray formation

- 1. Rapidly rotating black hole**  
The spinning black hole, surrounded by a swirling disc of matter, is thought to be created by the collapse of a massive star's core
- 2. High energy jets**  
Energetic particles from the rotating black hole shoot out in the form of high energy jets of excited particles
- 3. Supernova shell**  
The collapse of the massive star's core causes an explosion that ejects the outer layers of the star at high speeds, producing a shell. The interaction of the jet with this supernova shell produces an X-ray afterglow which can last for days or even months





## Anatomy of a star

### Core

The core of stars is where the vast majority of their nuclear fusion reactions take place. Temperatures are incredibly high, often over 10 million degrees Celsius (18 million degrees Fahrenheit)

### Magnetic field

Magnetic fields permeate all stars, with magnetic field lines arranged according to local conditions. Earth's Sun has a dipole magnetic field. These fields are commonly distorted by the star's internal dynamo

### Radiative zone

Each star has a radiative zone where energy from the core is directly radiated outwards through its gaseous material. Low-mass stars have radiative inner layers, while high-mass stars have radiative outer layers

### Subsurface flows

Subsurface flows are driven by both the distorting effect of the star's dynamo and also, on low-mass stars, by large convection zones that unstably transfer energy to the near surface in circular motions

### Convection zone

Driven by the fluid motion within the star's shells, convection zones are the secondary energy transportation process within stars. They only occur when radiative heat transfer is ineffectual, due to a high opacity of shell material





# What happens inside a star?

While the surface of a star – known as its photosphere – appears a busy place, it is nothing compared to its interior, which is a hive of physical processes

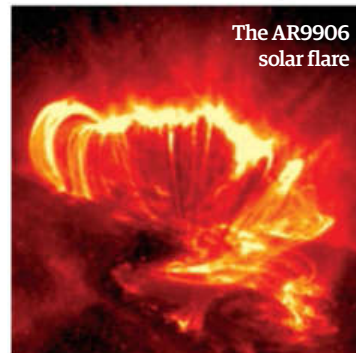
First, there is the process of hydrostatic equilibrium, which largely determines the star's density structure and is a counteracting sequence where the star's internal pressure gradient pushes against and counteracts the force of gravity. In essence, this determines the stability of the star's shell structure, its various rings of material (such as plasma) and forces emanating from the core. Without this stability, the various shells of the star will either contract or expand. For a star like our Solar System's Sun, the hydrostatic balance is finely tuned, as the star has been stable for over 7 billion years. However, for a star such as red supergiant Betelgeuse, it is not, hence the uneven shell structure.

The second key physical process within stars is energy transportation, which is important as the temperature of its gas determines the density structure via its hydrostatic equilibrium. The transportation of

energy within stars can happen via two processes, either by radiation or convection. In main sequence stars – such as our Sun – these processes are typically localised in radius to specific zones, with their position determined by the star's mass and shell opacity. Stars with masses over seven times that of the Sun are convective in their inner layers, while radiative in their outer ones due to their high internal mass. In contrast, stars with low mass, tend to be radiative in their inner layers but convective in the outer layers as their opacity is lessened due to their lower internal mass.

Finally, the third key process within stars is nuclear fusion, a series of reactions which occur primarily in the star's core (see the 'Fusion power explained' boxout for more information). These fusion reactions necessitate high temperatures in excess of 10 million degrees Celsius (18 million degrees Fahrenheit) and

high densities greater than hundreds of grams per cubic centimetre. Interestingly, the more massive a star is the shorter its life span becomes, as the nuclear fusion in its core occurs at a far quicker rate despite the increased quantity of fusible material. As such, stars of similar size to our Sun will have a main sequence of approximately 10 billion years, while a star ten times as massive would only last around 20 million years. ■



## Stellar dynamos

Many stars have a solar dynamo – vast rings of electrically conductive plasma that are charged through a shearing effect between different parts of the star rotating at different speeds. This shear charges the plasma to such an extent that they can warp the magnetic field lines.

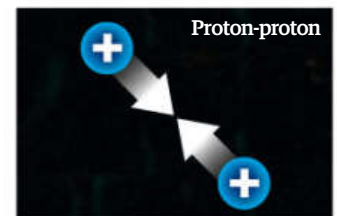
This distortion is so severe that the magnetic field lines tend to be dragged along with the fluid in a whipping motion. Indeed, it is because of this distorting effect that many stars demonstrate sunspot cycles, with the star's dynamo extending its field lines so much that they pierce the surface of the photosphere.

Solar dynamos are created by different parts of a star rotating at different speeds

## Fusion power explained

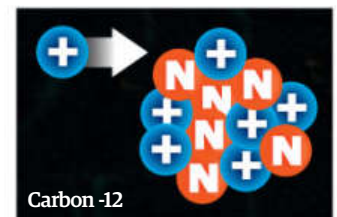
### Proton-proton fusion

A nuclear fusion process that fuels stars with core temperatures less than 15 million Kelvin, proton-proton fusion is a common reaction. It entails two protons fusing, with one being transmuted to a neutron, forming deuterium. The deuterium then fuses with another proton, generating a helium nuclei, two of which then fuse to generate an alpha particle and the release of two protons.



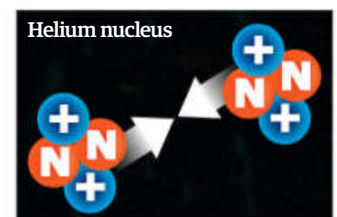
### Carbon fusion

For stars with central temperatures over 15 million Kelvin, carbon fusion tends to be the dominant process. It revolves around adding protons to carbon and then nitrogen over multiple sequences. The end result is the generation of an oxygen-16 atom, which emits an energetic alpha particle. This is not a major part of the Sun's reaction cycle, but is prevalent in the star Sirius.



### Helium fusion

If the core temperature of a star exceeds 100 million Kelvin, as is typical of red supergiant stars, then helium-helium can become the dominant reaction. This involves two helium nuclei fusing to create beryllium-8 and emitting gamma rays, before the beryllium-8 fuses with another helium nucleus and generates carbon-12, which unlike beryllium is stable.





# HOW PLANETS FORM



## Discover how our home, along with our Solar System neighbours and every other planet in the universe, was born from a chaotic cloud of dust and gas

In a sense, planetary birth is a side effect of a larger birth: the formation of a star. Stars form from nebulae, massive clouds of gas and dust dominated by hydrogen and helium. Now and then, a disturbance in a nebula concentrates an area of gas and dust into a denser knot of material. If the knot is big enough and dense enough, it will exert enough gravitational pull to collapse in on itself. The huge volume of super-dense gas concentrates at the knot's centre, and the gravitational energy heats it up to form a protostar. With sufficient mass, the energy of the protostar increases, eventually initiating a nuclear fusion reaction and graduating to a proper star.

Meanwhile, according to the solar nebula theory, surrounding gas and dust form a protoplanetary disc, or protoplanetary disc, around the protostar. When the protostar first begins to form, the surrounding material is still an unordered, slowly churning cloud. But the protostar's growing gravitational pull accelerates the cloud's movement, causing it to swirl around the centre. As the swirling mass speeds up, it flattens out, forming a thin disc, packed with all the material that will eventually coalesce into planets.

As well as explaining how planets form, the solar nebula theory also explains why solar systems take the form they do. The planets all revolve in the same direction around a central star, in the same plane, because that's how the material disc originally swirled around the protostar.

Exactly how it all comes about is still up for debate, and there may

actually be many different planet formation processes. The prevailing understanding, called the accretion model, is that planet formation begins when individual bits of matter in the disc clump together into bigger chunks. The accretion model seems to be correct at least in the case of rocky terrestrial planets, like Earth and Mars, which form from silicates and heavier metal, such as iron and nickel.

Astronomers generally agree that a planet like ours begins with an invisible piece of dust. Microscopic grains in the disc grow by condensation, the same process behind snowflake formation. In condensation, individual heavy gas atoms or molecules stick to a grain, rapidly expanding its size into a more substantial solid particle.

When the particles are very small and light, turbulent gas motions stir them up, swirling them outside the flat plane of the protoplanetary disc. But when they reach sufficient mass they're heavy enough to settle into the relatively thin rotating disc. In the crowded disc, particles collide more frequently, speeding up the growth of larger and larger chunks.

At about the point a chunk of solid matter grows to a kilometre across, it graduates to a planetesimal. A planetesimal is massive enough that its gravitational pull attracts smaller chunks of matter, accelerating the rate of growth. The result is a relatively small number of planetesimals steadily capturing the smaller chunks and particles in the disc.

When a terrestrial planetesimal grows large enough, the energy of



many collisions along with radioactive material it's accreted heat everything to melting point. As a melted mass, the planetesimal's structure can reform. In a process called differentiation, the force of gravity concentrates the melted metals into an inner core, surrounded by an outer crust of lighter rocky silicates. The result is a protoplanet, an asteroid-like mass with distinct layers. Over time, gravity evens out the protoplanet's shape, forming it into a sphere.

A terrestrial planet might form an atmosphere layer through outgassing. Essentially, heat from the planet's interior core unlocks gases trapped in the planet's solid and molten interior. Planets might then add to this atmosphere through encounters with other solar system bodies.

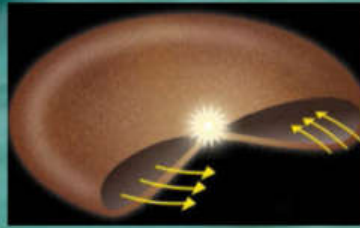
As the diversity of our own Solar System demonstrates, atmospheres vary a great deal. Any particular atmospheric recipe requires not only the right mix of planetary matter, but also a precise balance of planetary size and proximity to the central star. When a smaller planet orbits very close to a star, like Mercury, the Sun's heat blasts away any atmosphere, leaving a barren rock. Meanwhile, a planet like Mars is so far from the Sun that all its water is locked up in ice. But just a bit further in, you get Earth - a planet that's the right size and in the right position to form a robust atmosphere that could support life.

While there is general agreement among astronomers that terrestrial planets formed along these lines, the origins of Jovian gas giant planets, like Jupiter and Saturn, are less certain. One possibility is they start out the same basic way as terrestrial planets, steadily accreting solid matter to form a massive protoplanet. If it grows large enough - about 15 times the size of Earth - such a protoplanet exerts a strong enough gravitational pull to capture hydrogen and helium gas in the protoplanetary disc. The gaseous mass then sweeps up more material, growing into a Jovian behemoth.

There is a relatively small supply of heavy metals and silicate in a protoplanet, making it unlikely that a protoplanet could accumulate enough metal and rocky material to reach the size necessary to hold on to hydrogen and helium gas. Instead, this model says, the initial planetary core of a Jovian planet forms out of frozen hydrogen compounds, such as methane, ammonia and water. Near the centre of a protoplanet, the developing protostar makes it too hot for hydrogen

# Origins of a solar system

## Gas giant, the accretion model



**1. Dirty snowballs**  
Dust grains and bits of frozen hydrogen compounds condense and then collide and stick together, forming bigger and bigger icy planetesimals.

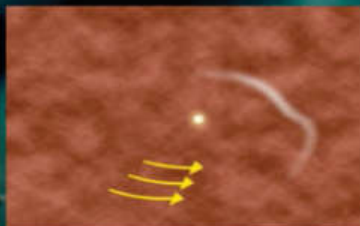


**2. Capturing gas**  
Some planetesimals grow so big that their gravitational pull captures hydrogen and helium gas in the protoplanetary disc.



**3. Too big to fail**  
The gas giants grab a huge supply of the disc's hydrogen and helium gas. Their massive gravity pulls in or scatters remaining planetesimals.

## Gas giant, gas collapse model



**1. Concentrations in the disc**  
In the disc of gas and dust that forms around a protostar, the dynamics of the rotation cause uneven distribution of hydrogen and helium gas.



**2. 'Instant' planet**  
A clump of dense gas collapses under its own gravity to form a gaseous planet. The new planet picks up dust and ice, which collect into a solid core.



**3. Glutton for gas**  
As the planet makes its way around the disc, its strong gravitational pull sweeps up more gas, making it bigger and bigger.



## A star is born

Astronomers believe a solar system begins when part of a nebula – a molecular cloud of gas and dust – collapses under its own gravity, forming a dense, hot core that becomes a star

## Gas giants

Further away, hydrogen compounds form ice, providing much more planet-forming material. The gravitational pull of much larger planets holds on to hydrogen and helium gas, forming a gas giant like Jupiter or Saturn

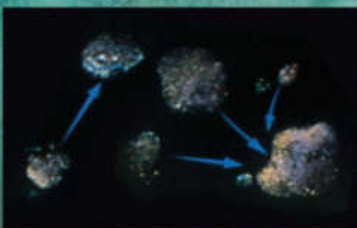
## The protoplanetary disc

As the star forms, its gravitational pull accelerates and flattens the surrounding molecular cloud, forming a spinning disc of material, which gradually coalesces into planets

## Terrestrial planets

Closer to the star, dust particles of heavier metals and minerals like iron and nickel clump together into larger and larger chunks, slowly forming rocky planets

# A terrestrial world is born



### 1. Let's stick together

Mineral and metal dust particles throughout the molecular cloud collide and clump together, forming larger rocky particles.



### 2. Running with the crowd

As trillions of these particles rotate around the developing star, they're constantly colliding, forming bigger asteroid-like pieces through accretion.



### 3. Forming a planetesimal

When a rocky chunk grows to about 1km across, its gravitational pull is able to attract other pieces, speeding up the accretion process.



### 4. Graduating to a protoplanet

Intense heat melts the rocky material. During melting, elements like iron and nickel concentrate at the centre of the planet, giving it distinct layers.

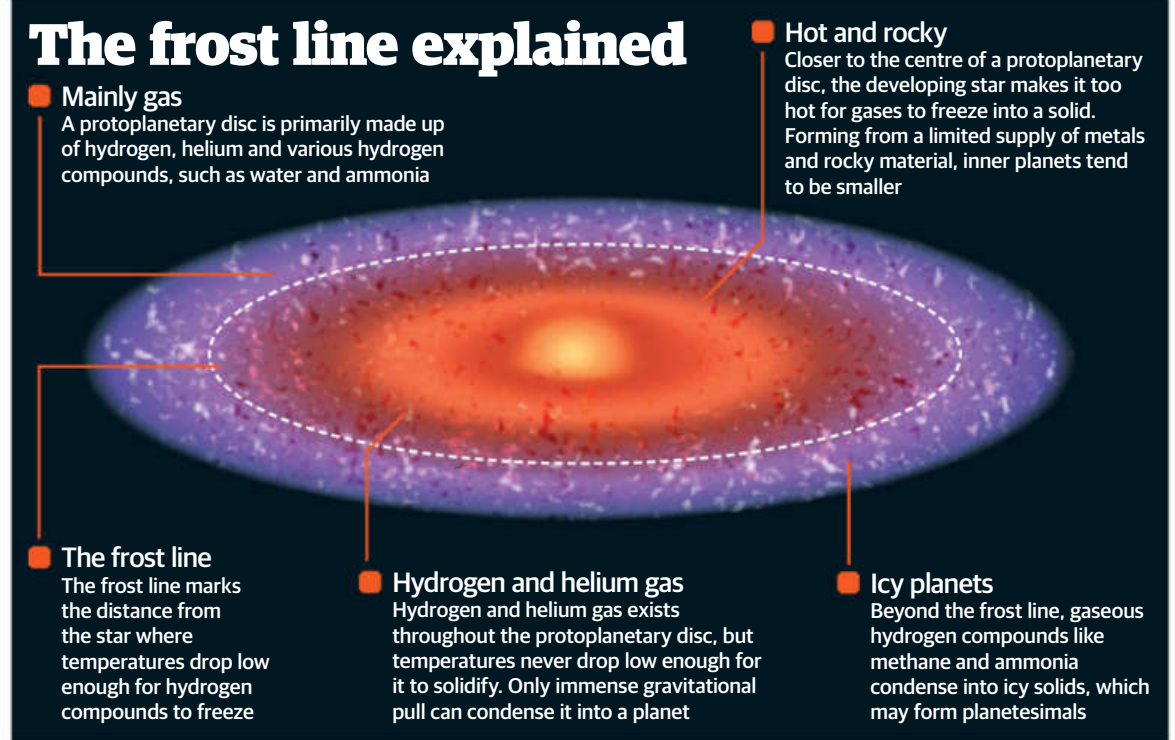


compounds to condense into frozen solids. They remain in gaseous form and so do not accrete to developing planetesimals. But if you move far enough away from the hot protostar, past what's called the frost line, the temperature drops low enough that hydrogen compounds can freeze. With a much more abundant supply of solid material, large icy protoplanets can form and capture the swirling hydrogen and helium gas.

The organisation of our Solar System supports this theory. The inner planets, Mercury, Venus, Earth and Mars are all relatively small and rocky, suggesting forming giant icy or gaseous planets wasn't possible close to the Sun, while the outer planets, Jupiter, Saturn, Uranus and Neptune, are much larger.

The chief argument against the accretion model for Jovian planets is timing. In well-supported models of solar system evolution, there simply isn't enough time to grow the massive icy cores before the developing solar system loses the bulk of its hydrogen and helium gas supply. While the lighter gases are the dominant material during the protoplanet's early life, their days are numbered. In the case of our own Solar System, some 10 million years after the Sun first formed as a protostar, the energy of nuclear fusion reactions likely produced powerful solar winds that would have cleared out the remaining gas in the protoplanet. That's a tight window for Jovian gas giants to form.

And neighbouring stars may lead to the window shrinking even further. Astronomers believe that stars generally form in clusters that contain massive, hot stars. Calculations say radiation from these stars would accelerate the evaporation of gaseous material in nearby protoplanets, shrinking the period of plentiful hydrogen and helium to between 100,000 and 1 million years. That doesn't appear to



be enough time for a Jovian gas giant to form through the accretion model, yet observations of distant solar systems show that these gas giants are very common.

An alternative theory, known as the gas collapse model, presents a faster formation scenario. According to this model, gas giants form directly from the swirling hydrogen and helium in a developing protoplanet. As the material revolves around the protostar, turbulence in the disc distributes it unevenly. This unevenness forms knots of dense gas. When enough gas is concentrated tightly enough, its dense mass causes it to collapse in on itself, forming a giant gas ball. To put it another way, the gas giant is like a failed star. It forms the same basic way as the protostar, but doesn't have sufficient mass and energy for a nuclear fusion reaction.

The embryonic planet's gravitational pull takes over from there, sweeping up massive amounts of gas, as well as any solids in the vicinity, quickly adding to its bulk. Collected ice and metals condense at the planet's centre, forming a solid core after the gas has accumulated, rather than before. The whole process might happen as quickly as a few hundred years.

Observations of Jovian exoplanets (planets located outside our Solar System) have given some credence to this model – or at least challenged the Jovian accretion model. In the wave of exoplanet discoveries over the past 25 years, one of the biggest surprises has been the so-called 'hot Jupiters', Jovian gas giants that orbit very close to their suns. These planets would seem to contradict the notion that gas giants only form beyond the frost line. However, they may have formed

further out, but then migrated towards their suns.

A host of exoplanet discoveries have given astronomers a much bigger picture of the range of possible planets, which has yielded new clues about how planets might form. But examining the end results can only tell them so much. Fortunately, we're likely entering a new era of direct protoplanet observation, thanks to advances in telescopic technology. The new Atacama Large Millimeter/submillimeter Array (ALMA) radio telescope in Chile, which should be fully operational in March, has already yielded unprecedented images of planet formation in progress. As new discoveries follow, astronomers expect to fill in more pieces of the puzzle, taking us ever closer to understanding how our planet, and by extension all of us, came to be. ●

## Types of planets

### Terrestrial

Terrestrial planets like Earth and Mars are rocky planets with metal cores and high densities. They are smaller than gas giants and have slower rotation periods. In addition, their smaller size means they are less likely to have moons.



### Gas giant

At a further distance from their orbiting star, gas giants are able to accrete more matter in their formation, giving them a large size and mass. For example, Jupiter is 11 times larger than Earth, and has a volume 1,300 times greater.



### Dwarf planet

Smaller than a true planet, the difference between an asteroid and a dwarf planet comes down to its shape. To be a dwarf planet, a body must have sufficient mass to achieve hydrostatic equilibrium, when it will become spherical.





## Planet formation in action

Our nearest star-forming region is the Orion Nebula, a massive cloud of gas and dust around 1,500 light years away. The striking nebula is visible to the naked eye - and positively breathtaking as seen through the Hubble Space Telescope. Hubble's sharp images, like this one from 2009, have revealed 42 protoplanetary discs (proplyds) where planet formation is now in progress. Theta<sup>1</sup> Orionis C, the nebula's brightest star, heats nearby proplyds, giving them a bright glow. Proplyds forming further away are too dim to see, but their dark dust blocks out parts of the bright nebula in the background, creating silhouettes astronomers can study.



132-1832  
Developing far from Theta<sup>1</sup> Orionis C, 132-1832 is one of the darker proplyds in the nebula



206-446  
Astronomers believe this bright proplyd's distinctive ponytail-style plume is a jet of matter streaming out from the disc's centre



106-417  
Stellar wind from the massive Theta 1 Orionis C interacting with gas has formed a shockwave around this ear-shaped proplyd



180-331  
Proplyd 180-331, another bright disc near Theta<sup>1</sup> Orionis C, also sports a flowing jet of matter, giving it a tadpole shape



181-825  
But the best shockwave sculpture has to be 181-825's distinctive galactic jellyfish form



231-838  
Like 106-417, the bright proplyd 231-838 is surrounded by a shockwave, giving it a boomerang shape

"The origins of Jovian gas giant planets, like Jupiter and Saturn, are less certain"



# What are asteroids made of?

The physical properties of huge space-rocks whirling around the Sun could hold clues to the origins of the Solar System





Protecting Earth is one of the main reasons why scientists keep a close eye on asteroids, which are space rocks of all shapes and sizes that can be found scattered throughout the Solar System.

It's unclear how meteoroids, the rocks that become meteors when they crash into Earth's atmosphere, were generated from asteroids. Still, NASA isn't ruling a link out and is examining asteroids to learn more about how the Solar System was formed.

Since planetary scientists believe planets gradually grew from rocks crashing into each other, the asteroid belt between Mars and Jupiter could be made up of the leftovers of the early Solar System.

Therefore, ferreting out the secrets of asteroids could also give scientists clues as to how the Solar System came to be. Possibly, it could even reveal how the Earth was born.

Studying asteroids is a challenge for scientists, however, because they are so small. A typical space rock is perhaps just a few metres across. However, the largest known asteroid in our Solar System, Ceres, is 950 kilometres (590 miles) in diameter and makes up a third of the mass of the known asteroid belt. However, through a telescope sitting on Earth, an asteroid of this size looks incredibly small. This makes asteroids difficult to see and study, but scientists are pretty crafty when it comes to getting information from a distance.

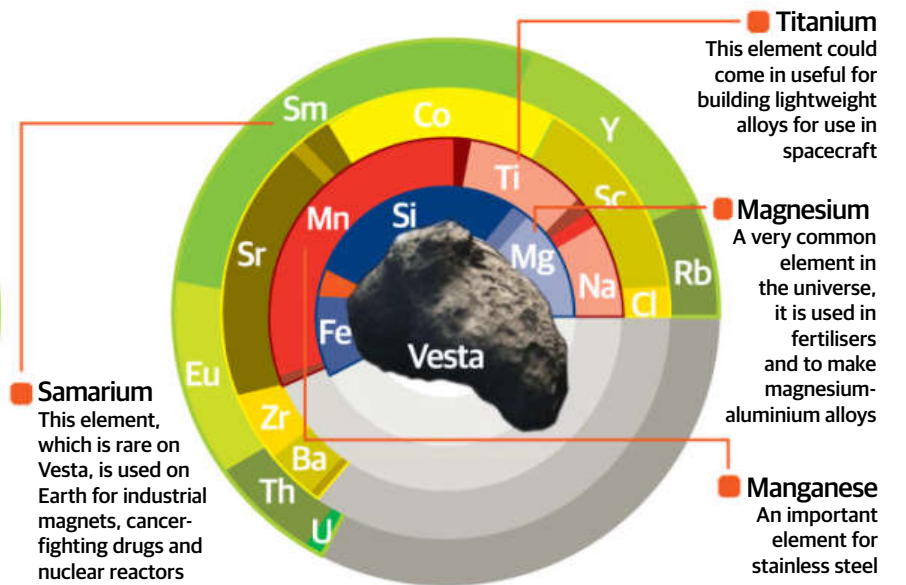
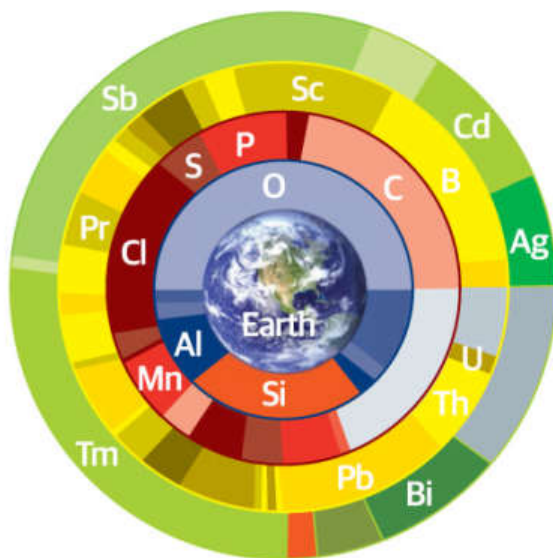
Most asteroids, according to NASA, can be classified in three groups: C-type (carbonaceous), S-type (siliceous) and X-type (various compositions). Around 75 per cent are C-type asteroids that lurk in the outer asteroid belt. They are very dark and probably lack helium, hydrogen and other lighter

"In 1995, there were only 335 known near-Earth asteroids, however, today there are more than 9,700 catalogued"



Asteroid Ida and its moon, Dactyl. The spacecraft Galileo discovered the small moon when it passed by the asteroid in 1994

## Explaining the elements



Ag - Silver  
Al - Aluminium  
B - Boron  
Bi - Bismuth  
C - Carbon  
Cd - Cadmium

Cl - Chlorine  
Mn - Manganese  
O - Oxygen  
P - Phosphorus  
Pb - Lead  
Pr - Praseodymium

S - Sulphur  
Sb - Antimony  
Sc - Scandium  
Si - Silicon  
Th - Thorium  
Tm - Thulium

U - Uranium

Ba - Barium  
Co - Cobalt  
Cl - Chlorine  
Eu - Europium  
Fe - Iron  
Mg - Magnesium

Mn - Manganese  
Na - Sodium  
Rb - Rubidium  
Sc - Scandium  
Si - Silicon  
Sm - Samarium

Sr - Strontium  
Th - Thorium  
Ti - Titanium  
U - Uranium  
Y - Yttrium  
Zr - Zirconium

**Titanium**  
This element could come in useful for building lightweight alloys for use in spacecraft

**Magnesium**  
A very common element in the universe, it is used in fertilisers and to make magnesium-aluminium alloys

**Manganese**  
An important element for stainless steel

**Samarium**  
This element, which is rare on Vesta, is used on Earth for industrial magnets, cancer-fighting drugs and nuclear reactors



Asteroids can range from just a few metres wide to almost 1,000km in diameter

'volatile' elements. S-type asteroids, about 17 per cent of the population, make up most of the inner belt rocks in the asteroid belt. They're a little more reflective and are usually made of metallic iron mixed with silicates of iron and magnesium. Squeezed in between these asteroids are X-types, which are mostly made up of metallic iron asteroids and the like. These are found in the middle of the asteroid belt.

While most asteroids sit safely between Mars and Jupiter, some approach Earth and sometimes cross its orbit. Scientists think most of these asteroids were 'disturbed' into different orbits due to Jupiter's gravity or collisions with other asteroids.

There are three types of near-Earth asteroids. Amors cross the orbit of Mars, but don't get very close to Earth. Apollos cross Earth's orbit in a period of one year or longer, while Atens also cross the orbit but in a shorter time frame - a year or less.

In the past two decades, space agencies and observatories around the world have discovered thousands of these types of asteroids. In 1995, there were only 335 known near-Earth asteroids, however, today there are more than 9,700 catalogued, according to NASA.

Since scientists believe we have now found more than 90 per cent of threatening asteroids that are more than one kilometre (0.6 miles) in diameter, NASA is now emphasising the search for finding near-Earth objects of 140 metres (460 feet) or greater.

Still, a much smaller object can cause a lot of damage. The dinosaurs were probably wiped out by a small body just ten kilometres (6.2 miles) in diameter that hit the Mexico area about 66 million years ago.

In Russia this year, more than 1,000 people were injured when a house-sized asteroid - 17 metres wide (56 feet) - detonated in the atmosphere. The event caught both the public and astronomers by surprise, demonstrating we still have a lot to learn about predicting meteor strikes on Earth.

In more recent years, several space missions have ventured out to asteroids to get more information from closeup. NASA's Dawn mission, for example, scooted by the asteroid Vesta in 2011 and is now en route to Ceres.

Its closeup views revealed a battered world that, surprisingly, has some links to how the Moon was

formed. Vesta and the Moon were each peppered by a population of space rocks ejected into the inner Solar System early in the Earth's history.

Both Jupiter and Saturn shifted their orbits in less than a million years. Their motions perturbed the asteroid belt and sent the rocks into planet-crashing orbits. This bombardment had been known about for decades - astronauts on the Apollo missions even discovered evidence of it on the Moon - but

scientists didn't know until recently that Vesta had also experienced it.

The next step will be obtaining a sample of an asteroid and studying it here on Earth. Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) will journey into space in 2016, scoop up a bit of dirt from the Apollo asteroid (101955) 1999 RQ36, and return it to Earth by 2023 for further investigation. ■

## What lies inside

**Asteroid Vesta** ■  
Vesta, the second-most-massive asteroid in the Solar System, stands in a class of its own called V-type asteroids. They tend to contain more pyroxene than S-type asteroids

■ **Core**  
Data from the Dawn mission showed that Vesta has a core of 110km (68mi) in radius. The core is mostly made up of iron

■ **Crust of Vesta**  
Vesta melted at some point early in its history, producing a 'differentiated' core and a basaltic crust

■ **Mantle**  
Vesta's mantle, wedged between the core and crust, likely includes olivine and diogenite

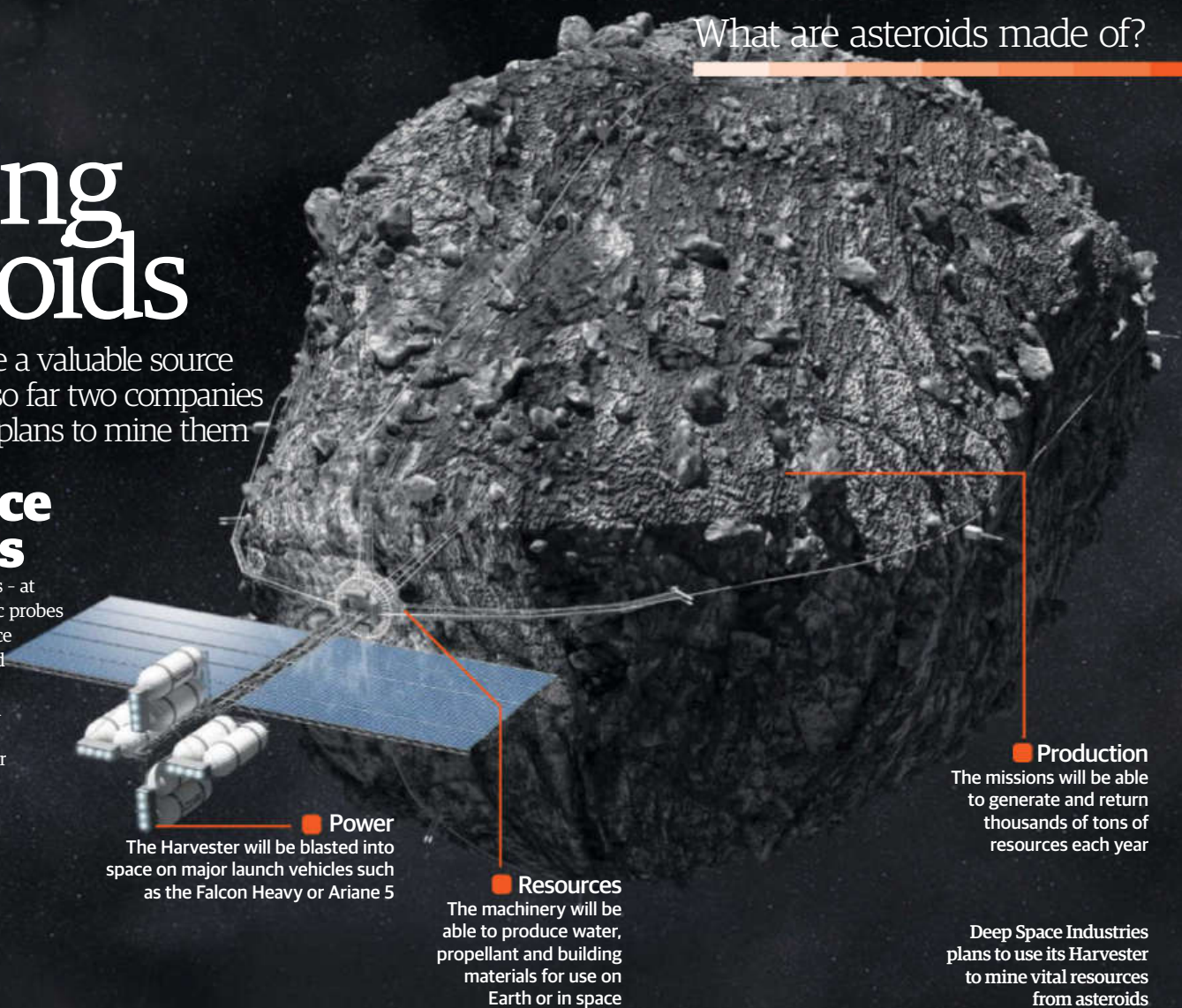


# Mining asteroids

Asteroids could be a valuable source of resources and so far two companies have announced plans to mine them

## Deep Space Industries

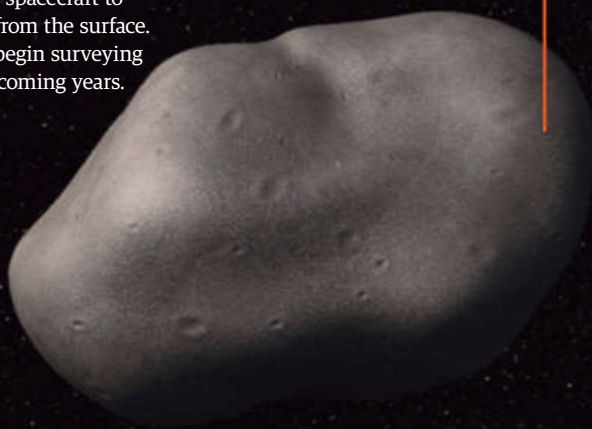
Deep Space Industries plans - at some point - to send robotic probes on a one-way reconnaissance mission to potential asteroid mining sites. Later, larger DragonFly spacecraft would potentially pick up samples or small asteroids for further evaluation on Earth.



Deep Space Industries plans to use its Harvester to mine vital resources from asteroids

## Planetary Resources

Planetary Resources first plans to scope out potential asteroids using a telescope. They will then capture a suitable asteroid and reposition it in a stable orbit near Earth, before sending a fleet of robotic spacecraft to return samples from the surface. They expect to begin surveying asteroids in the coming years.



**Resources**  
Groups of robots will scour the asteroid to retrieve its resources



**Capture**  
Once they've found a suitable asteroid Planetary Resources will capture it to begin mining





5

AMAZING  
FACTS  
ABOUT

# Moon dust

© NASA



Astronaut Harrison Schmitt scoops samples of lunar dust and rock during the Apollo 17 mission to the Moon in 1972

### 1 You shouldn't breathe it

Following a lunar walk, astronaut Harrison Schmitt noted the smell of Moon dust in the air, like gunpowder. NASA pathologist Russell Kerschmann warned that prolonged exposure to Moon dust could seriously damage human lungs.

### 3 It wears through spacesuits

Moon dust is very abrasive and clingy. Apollo 17 astronauts had problems moving their arms properly because lunar dust had clogged up the joints, while it wore through three layers of Kevlar-like armour on Harrison Schmitt's Moon boot.

### 4 It's actually mostly glass

Lunar dust is mostly made up of very fine particles of silicon dioxide glass, plus iron, calcium and magnesium, as well as other trace minerals. It's all been shattered and ground into a fine powder over billions of years of meteorite impacts.

### 2 It's magnetic

Because tiny specks of iron are present in the glass shell of each lunar dust particle, magnets can be used to filter the dust out of the air and off sensitive equipment. The dust that makes up lunar soil can also be quickly microwaved into flat sheets, meaning roads and landing pads can easily be created for future missions.

### 5 Astronauts have tasted it

In the interests of science (as well as pure human curiosity), Apollo astronauts have touched, smelled and even tasted Moon dust. Apparently, it's as fine as flour but abrasive, plus it both smells and tastes like gunpowder. It's also clingy and hard to brush off.







# DEADLY SPACE JUNK

Hurtling around the Earth at thousands of kilometres per hour, out-of-control space debris can have a devastating effect on anything that crosses its path

It's perhaps the most electrifying sequence in the awe-inspiring blockbuster film *Gravity* - the moment a blizzard of incoming space debris travelling at terrifying speed lays waste to everything in its path, destroying both the International Space Station and an orbiting Space Shuttle, leaving two spacewalking astronauts adrift and fighting for their lives.

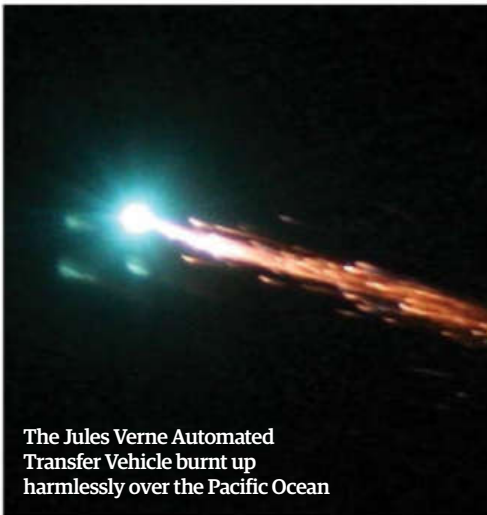
Fortunately, though, it's the kind of thing that could only happen in a movie... or is it? While the

debris storm in *Gravity* is created by a foolhardy missile test on a defunct satellite, space scientists today are increasingly concerned that something very similar could happen by accident, with a runaway cascade of collisions leaving large areas of near-Earth space dangerously inaccessible. If that happens, the effects wouldn't just be felt by a few orbiting astronauts - we could all suffer the substantial consequences.

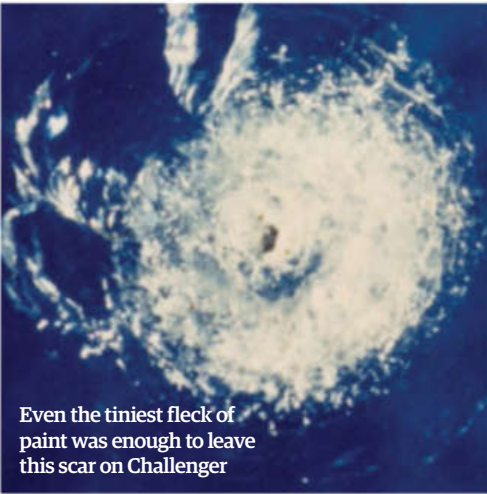
Ever since the launch of the first satellite, Sputnik 1, back in 1957, humankind has been steadily filling up the space around Earth. Official figures put the number of satellites sent into orbit since the dawn of the Space Age at nearly 7,000 and there are probably a few unacknowledged ones lurking around from the secretive days of the Cold War.

While many of these objects have since re-entered Earth's atmosphere and burnt up - thanks to either





The Jules Verne Automated Transfer Vehicle burnt up harmlessly over the Pacific Ocean



Even the tiniest fleck of paint was enough to leave this scar on Challenger

unstable initial orbits or the slight but inexorable drag of sparse gas in the upper atmosphere - an estimated 2,000 are still circling Earth today.

Given the sheer volume of space available around Earth, that might not seem like a large number, but there's a catch - satellites tend to cluster together in a much smaller number of particularly useful orbits. Low Earth Orbit (LEO), for example, is the zone just a couple of hundred kilometres above the surface that's most easily reached by manned spaceflight and also most useful for many Earth-observing satellites.

Geostationary orbit, meanwhile, is a very specific circular orbit 35,786 kilometres (22,236 miles) above the equator, in which satellites orbit the Earth in the same period as the planet itself rotates (23 hours, 56 minutes), therefore maintaining a fixed position in the sky as seen from Earth. The majority of weather satellites use this orbit, as well as telecommunications satellites that form such an essential part of the modern global infrastructure.

What's more, launching anything into orbit is a messy business, so even if the lower stages of a rocket simply arc into space before plunging back to Earth, there's every chance they could leave more behind than their intended payloads. Explosive bolts fired to separate launch vehicle components and the ignition of further stages may shake loose chips of paint and even larger fragments of rocket casings, flinging them into their own unpredictable orbits around Earth. Another major problem is that spent rocket casings, languishing idly in orbit, can suffer from spontaneous yet hazardous explosions.

Both NASA and the European Space Agency have programmes dedicated to tracking orbital debris - NASA's Ground-based Electro-Optical Deep Space Surveillance (GEODSS) project searches for material

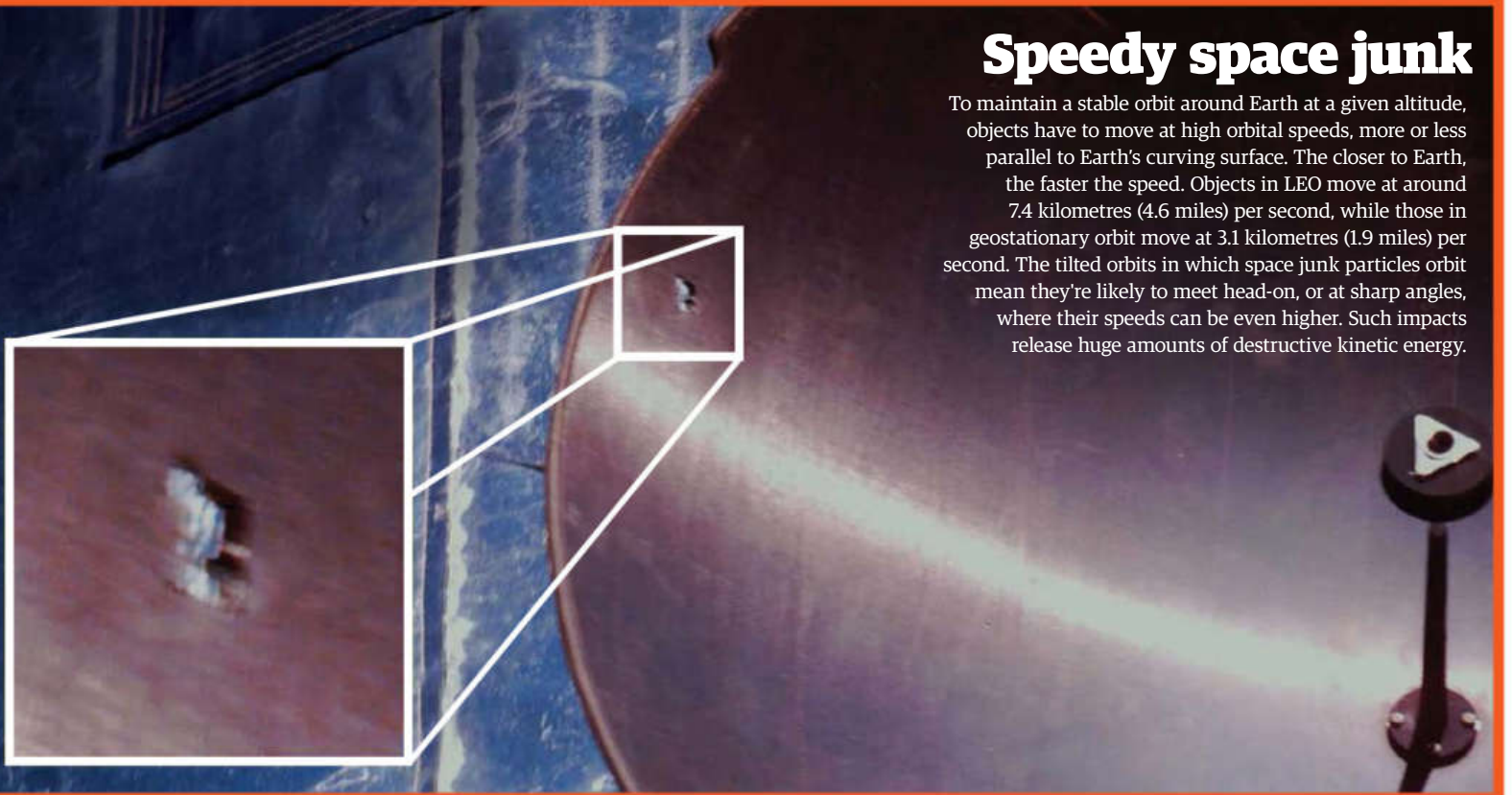
using an array of computerised optical telescopes and super-sensitive television cameras. The technology can only track objects of roughly ten centimetres (four inches) in diameter (with a mass typically around a kilogram, or 2.2 pounds), but GEODSS has so far identified 22,000 different objects in this class. Based on this figure, statistics suggest there could be as many as 500,000 objects in the one to ten-centimetre (0.4 to four-inch) range, plus tens of millions of smaller particles. Other surveys aim to use ground-based radar to track objects too small to be seen by optical telescopes. Maps produced using this data show our planet already surrounded by an alarming halo of debris.

Perhaps it's little wonder, then, that collisions happen. Space scientists received an alarming wake-up call to the growing threat in 1983 when the Space Shuttle Challenger returned to Earth with a substantial crater in one of its reinforced windows. Careful study of the damage back on Earth determined that it was caused by an insubstantial fleck of paint, colliding with the shuttle at several kilometres per second - it's the hypervelocity speed of encounters in orbit that enables even lightweight objects to pack such an unexpected punch.

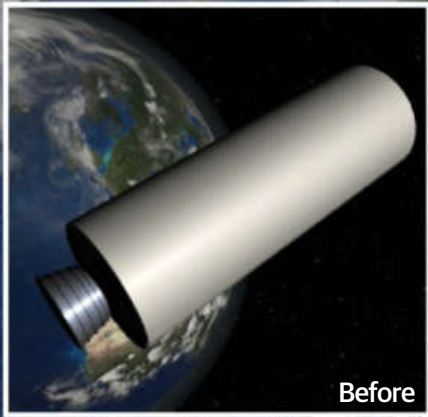
What's worse, the fairly frequent shuttle flights up to the end of the last decade gave engineers a chance to make regular assessments of the likelihood of impacts in LEO and provided clear evidence that the problem was getting worse - particularly since the late-1990s. In 2006, Atlantis was struck by a tiny object that bored a hole straight through one of the radiator panels on the cargo bay door, while in 2007 Endeavour came home sporting a hole several centimetres across in the same area, that triggered more than a slight cause for concern.

## Speedy space junk

To maintain a stable orbit around Earth at a given altitude, objects have to move at high orbital speeds, more or less parallel to Earth's curving surface. The closer to Earth, the faster the speed. Objects in LEO move at around 7.4 kilometres (4.6 miles) per second, while those in geostationary orbit move at 3.1 kilometres (1.9 miles) per second. The tilted orbits in which space junk particles orbit mean they're likely to meet head-on, or at sharp angles, where their speeds can be even higher. Such impacts release huge amounts of destructive kinetic energy.







Before

After

## Explosions in orbit

One of the most dangerous ways in which quantities of space junk can increase is when discarded rocket stages are left in orbit with fuel still in their tanks. In some cases, liquid fuel can simply evaporate until the pressure of the gas from within ruptures the rocket's hull. In others, the rocket's internal structure can deteriorate over time due to various stresses (such as the continued expansion and contraction driven by sharp temperature changes in space). Eventually, the barrier between tanks can break down, enabling different rocket propellants to mix with dramatic results - explosions that have the potential to fling out chunks of shrapnel with different masses and speeds into orbit.

An even more impressive collision took place in 2009, when Iridium 33 - part of the US satellite telephone network - collided with the defunct Russian communications satellite Kosmos-2251 at high speed. The two satellites were travelling almost perpendicular to each other and, in the months that followed, NASA tracked a spreading field of more than 2,000 substantial debris fragments. In March 2012, astronauts aboard the International Space Station were forced to take shelter, ready for an emergency return to Earth, as a fragment of the Russian satellite passed nearby.

Various space agencies have also done their best to add to the problem from time to time. The earliest example of deliberate orbital littering came with Project West Ford in 1963 - an attempt to scatter a ring of almost 500 million tiny magnetic needles around the Earth. It was thought this would form an artificial ionosphere - a reflecting layer for bouncing military signals between distant locations. Other shocking examples include the deliberate destruction of satellites during anti-satellite missile tests. China's destruction of its Fengyun-1C satellite during a 2007 weapons trial still holds the ignominious record as the source of the largest amount of catalogued debris.

Fortunately Earth's atmosphere provides a natural clean-up mechanism in the form of friction with the upper atmosphere or exosphere. Although objects in orbit can usually be considered as outside the atmosphere, the thin shell of gases has no abrupt edge - instead it extends out for thousands of kilometres, growing ever thinner. Friction caused by collisions with these sparse gas molecules gradually slows the orbits of satellites, dropping them closer to Earth, where they experience increasing friction. As a result, with no external intervention, most satellite orbits inevitably decay and objects re-enter the atmosphere. However, atmospheric drag is only really effective at clearing out orbits below about 800 kilometres (500 miles).

In the early days of space exploration, engineers mistakenly assumed that orbital decay would drain debris from orbit quicker than it could accumulate, but they reached this conclusion without considering two significant factors. The first of these is simply the increased accessibility of space and the number of satellite launches. The second, and more alarming problem, is the so-called Kessler effect.

Named after NASA scientist Donald Kessler, who in the 1970s predicted the development of a fully

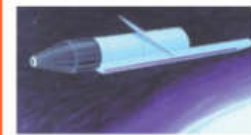
"Earth's atmosphere provides a natural clean-up mechanism in the form of friction with the upper atmosphere"

## Left in space



### Vanguard 1

The oldest piece of space junk still in orbit is Vanguard 1, the second US satellite. It stopped transmitting signals to Earth in 1964, but is likely to remain in orbit for another two centuries.



### Orbiting reactors

RORSAT was a series of spy satellites launched by the Soviet Union between 1967 and 1988. While the satellites have re-entered the atmosphere, their reactor cores were ejected into higher orbits.



### Lost tools

Space Shuttle astronauts had to cope with the embarrassing sight of a number of tools drifting away into space, including wrenches, pliers and on one occasion an entire toolbag!



# Space junk through the years

Since our first forays beyond the Karman line, around 100 kilometres (60 miles) above sea level, we've sent an exponential stream of objects, instruments and spacecraft into various levels of Earth orbit. For the best part of that time, we've not even thought about the mess we've been making up there or the consequences of space junk in the future.

Both the amount and different types of junk has increased dramatically in the last 30-40 years since the Apollo missions. Here's the kind of dangerous scrap every new space mission faces in orbit today...

## Key

- Each dot represents 100 objects with a diameter of more than 10cm

## Type of debris

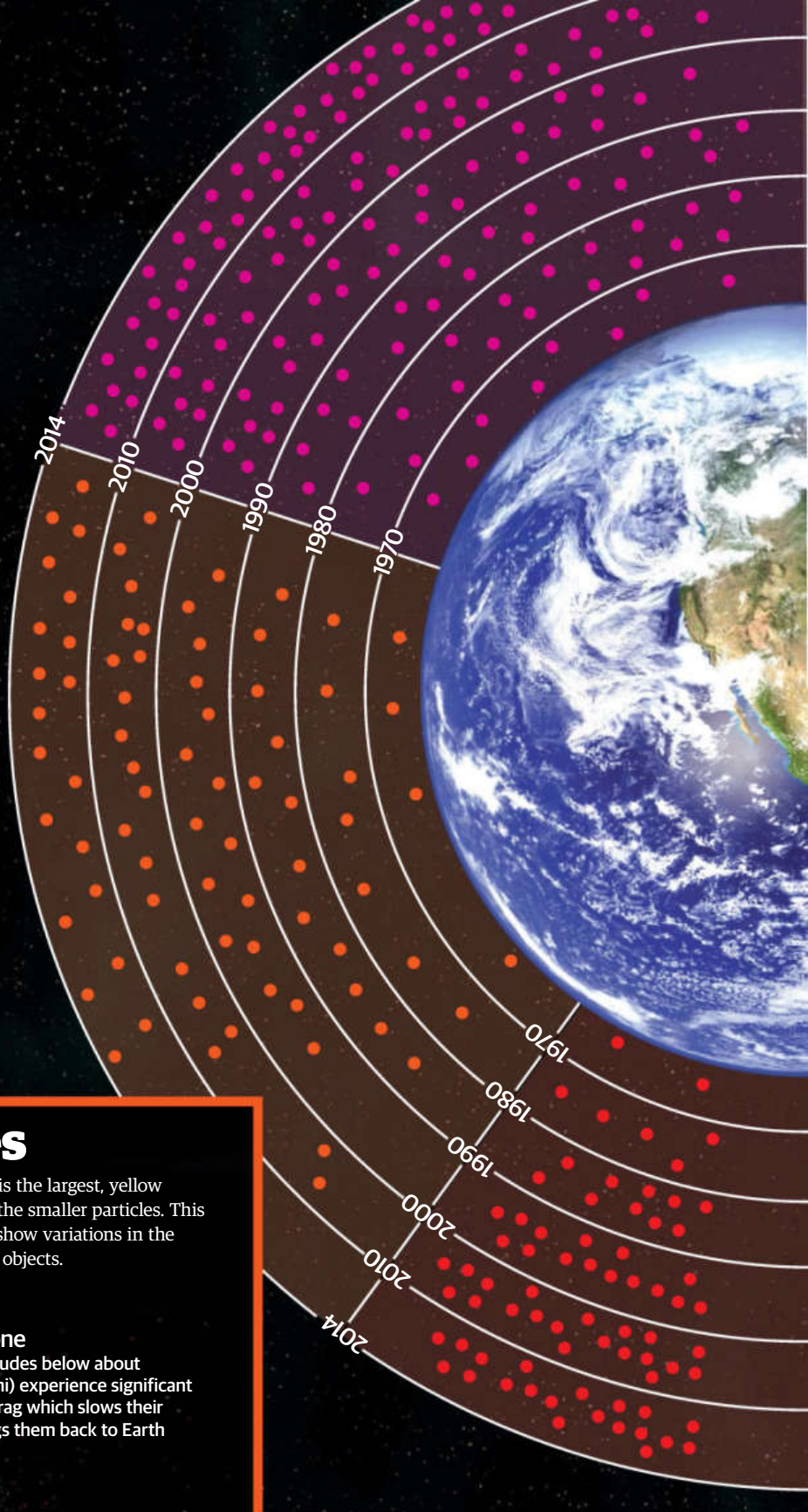
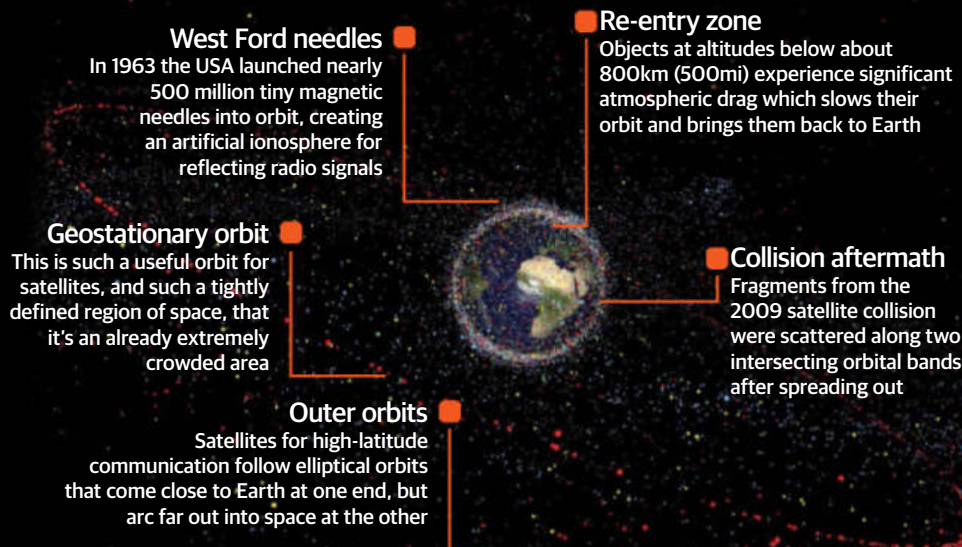
- Payloads
- Payload debris
- Rocket mission-related objects
- Rocket debris
- Rocket bodies

## Earth's deadly debris zones

This artist's impression attempts to visualise the crowded space around the Earth, highlighting the busiest regions, including LEO and geostationary orbits. Different sizes of object are represented

in various colours: red is the largest, yellow intermediate and blue the smaller particles. This view only attempts to show variations in the distribution of orbiting objects.

**Key** ● > 10cm ● > 1cm ● > 1mm



blown debris belt around the Earth by the turn of the millennium, Kessler syndrome is an effect in which, once the debris belt has reached a certain critical density, an initial collision between two large objects can give rise to a cascade, or avalanche, effect. This results in shrapnel being flung out from the first collision, hitting other objects in nearby orbits and generating yet more debris. Kessler was the first to recognise that one of the crucial factors controlling the density of objects was the rate of collisions between them, since a single high-energy collision shattering an asteroid could produce countless



## Space junk: the figures

**22,000**

The number of large objects less than 10cm across being tracked in Earth orbit by NASA's GEODSS system

**500K**

Statistical estimate of the mid-sized fragments (1-10cm across) in orbit around Earth

**3**

mm  
Size of the smallest debris fragments that can be seen by Earth-based radar monitoring

**1 in 200**

NASA's upper risk limit to the chances of a collision with a piece of debris on a mission

**13,000**

The estimated number of close calls that occur every week

**8,211**

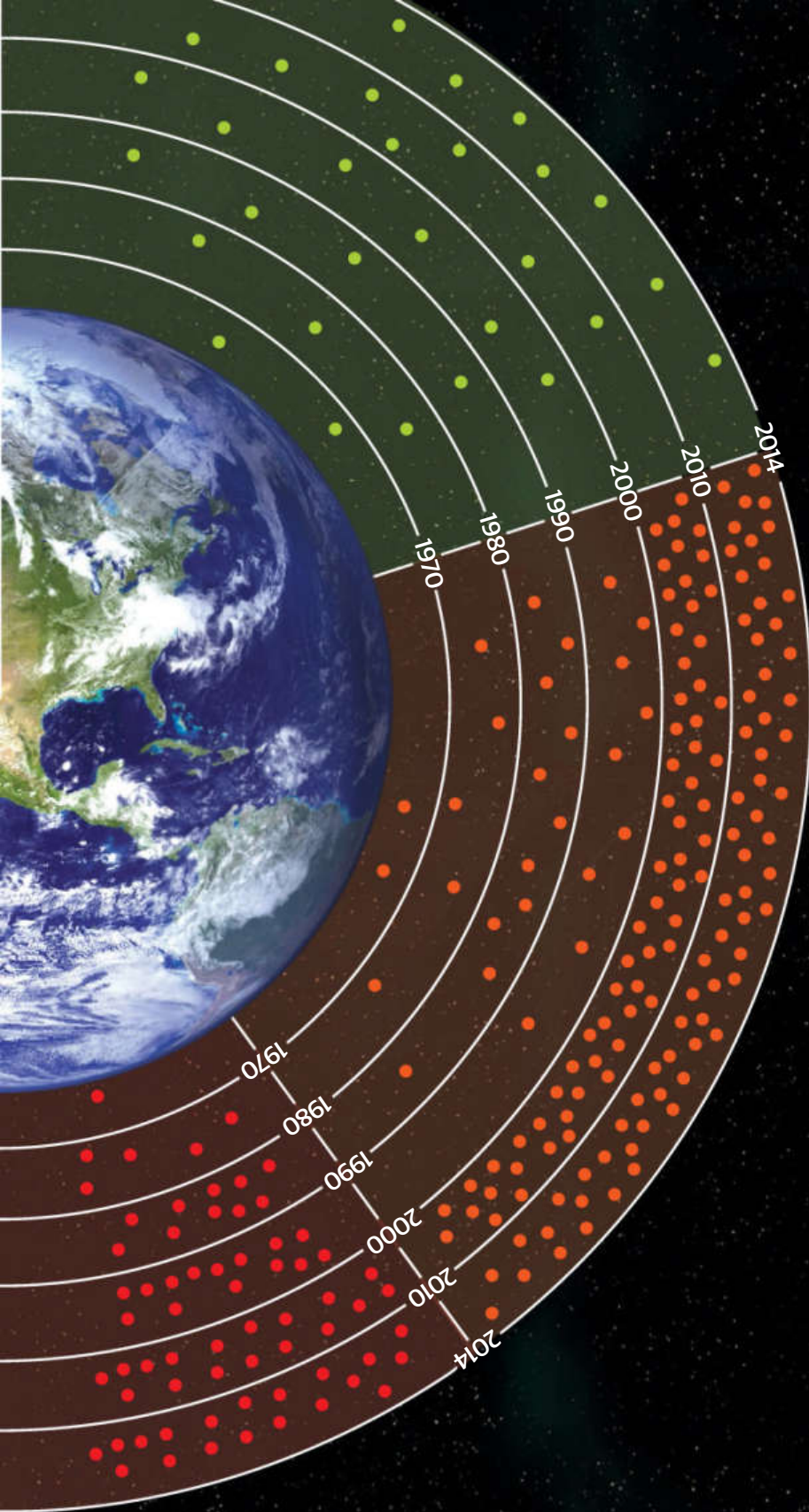
**3,000**

Number of trackable debris pieces created by the 2007 anti-satellite test

**kg**  
The mass of the Envisat satellite stranded in a crowded region of Low Earth Orbit

**42,120km/h**

Speed of the 2009 collision between Iridium 33 and Kosmos-2251



fragments, each of which, though small, might potentially be fatal to a spacecraft.

This is the kind of event dramatised in that pivotal sequence from *Gravity* and its overall result could be to render large areas of Earth orbit inaccessible for many years. While it's unlikely that a Kessler cascade could block access to space completely, it could make it harder to reach certain types of useful orbit and limit the operational lifetime of satellites after their deployment. These are all factors that could significantly affect everyday technologies such as satellite navigation, telephony and broadcasting,

as well as limiting scientific missions such as Earth remote sensing and orbiting astronomical telescopes.

So, in little more than five decades of spaceflight, we've already reached a situation in which space junk is a very real threat. It's one that's only likely to get worse in the future unless we take global action not just to improve our littering habits, but also to remove the material that's already there.

Satellites are increasingly being designed with the facility to boost into a safe, remote graveyard orbit at the end of their useful lives, or to deliberately deorbit, ensuring a safe, controlled breakup in the

atmosphere. Efforts have also been made to limit the dangers from potentially explosive debris left in orbit. There's even talk of regulating commercial satellite companies with a 'one up, one down' rule, so it's in their financial interest to ensure defunct spacecraft are safely and cleanly dealt with. The International Telecommunication Union (ITU), responsible for regulating comsats in geostationary orbit, has been particularly keen to ensure this valuable and very precise orbit is maintained for future use.

So, how can we clear out all the junk that's already up there? Various ideas have been put forward,



including automated tug spacecraft capable of boosting geostationary satellites into a graveyard orbit, or even returning them to Earth. However, this kind of mission would only really be practical for handling the largest pieces of debris - shifting material between orbits would require large amounts of propellant, so the tug design itself would require an infrastructure for refuelling in orbit.

An ingenious alternative, developed by researchers at Texas A&M University, is the Sling-Sat - a fuel-efficient mission that would involve a spinning satellite briefly capturing debris before flinging it away on a safe path towards de-orbit. Each interaction with a debris particle would increase the satellite's momentum, enabling it to remain in operation for a long period of time.

Dealing with the countless smaller debris fragments is a much greater challenge, so for practical reasons any clean-up operations will almost certainly be limited to certain specific clusters of small debris, such as those left behind by Project West Ford.

Many proposals involve deploying the space-based equivalent of a butterfly net. In February 2014, a joint US-Japanese satellite launched into orbit carrying a prototype for one such design. The Space Tethered Autonomous Robotic Satellite 2 (STARS-2) mission involves the deployment of a small subsatellite at the end of a 300-metre (984-foot) tether cable. Using the same principle as a bicycle dynamo, this tether will generate electric current as it passes through Earth's magnetic field and the resulting electromagnetic field around it should attract nearby debris particles, rather like a balloon with a static charge attracting dust. If the trial goes according to plan, a full-scale version could be in operation by 2019.

Another widely touted alternative is known as the laser broom, involving firing a medium-powered laser from the ground towards the front of debris particles. Working on the same principle as solar sail propulsion, the laser would apply a tiny braking force to the target object, gradually draining its momentum and pushing it onto a new orbit. Studies suggest that a laser broom could adjust the orbit of small objects by a couple of hundred metres over a few hours - enough to avoid potential collisions, while repeated use could nudge an object towards eventual deorbit. The accurate targeting of such small and fast-moving objects would be a major challenge so, for the moment at least, laser brooms might be most appropriate as a last line of defence for space stations.

One thing, it seems, is certain - with new players entering the field of space exploration and the valuable real estate of Earth orbit becoming ever more crowded, space junk isn't a problem that's about to go away any time soon - it's quite literally an accident waiting to happen. ■

## Clean-up operation

### Grappling in space

This artist's concept for a tug spacecraft uses a simple robot arm to grasp the target satellite, most of which are designed with grapple handles or docking points

### Final approach

Capturing a satellite from orbit requires a slow and accurate rendezvous for final docking, achieved using either radar or laser ranging

### Phasing

In the phasing stage of the mission, precisely timed rocket engine burns boost the apogee (highest point) of the tug's orbit towards its target

### Orbit & rendezvous

As the tug closes in on its target satellite, further precisely timed burns match the direction and speed of the two craft

### Commissioning

### Launch

A purpose-built space tug satellite is initially launched into a circular LEO with an altitude of about 300km (186mi)



## Step 1



### Trawling in orbit

Another possible way of capturing a satellite, illustrated in these two steps, involves the deployment of a large net or basket at the end of a long, flexible tether. Once the satellite is secured, the final phase of the mission can begin

## Step 2



### Target orbit

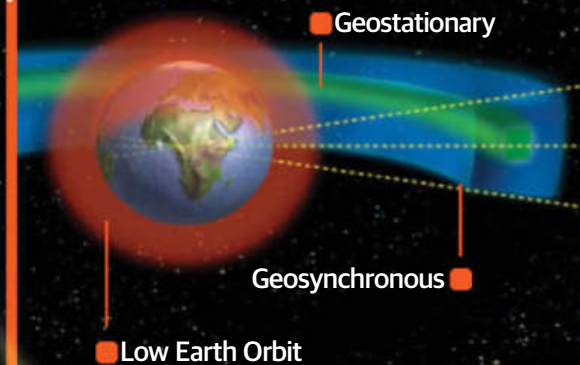
### Perigee lowering

The tug spacecraft reorients itself in space so that engine burns gradually slow its orbital momentum and lower its perigee (closest point to Earth)

## Protected orbits?

Since 1993, most of the world's major space agencies have been members of the Inter-Agency Space Debris Coordination Committee (IADC), a co-operative effort to research the effects of space debris and look at ways of resolving the problem.

One of their key proposals, first outlined in 2002, is the creation of protected orbital regions - zones where special efforts would be made to avoid debris creation - and to remove defunct satellites once their useful lifetime is at an end. The two key zones are LEO (defined as everything below an altitude of 2,000 kilometres or 1,243 miles) and the geosynchronous region covering a swathe 400 kilometres (249 miles) deep and 30 degrees wide around the exact geostationary altitude of 35,786 kilometres (22,236 miles). Geostationary transfer orbits used by satellites on their way to the geosynchronous region; IADC argues, should also be protected.

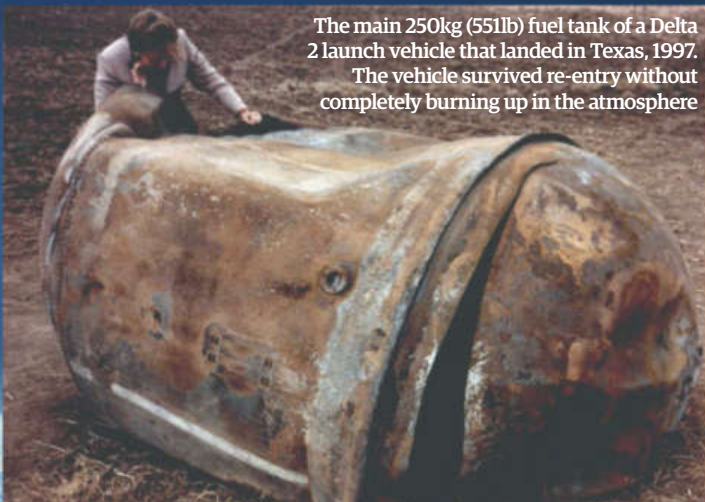


### De-orbit burn

With the perigee skimming the thicker layers of Earth's atmosphere, a final engine burn puts the tug and its cargo on target for re-entry

### Re-entry

Depending on the size of the spacecraft involved, both satellites may break apart and burn up amid the stresses of atmospheric re-entry. Alternatively, the de-orbit burn can be timed to ensure that any surviving fragments crash into the open ocean



The main 250kg (551lb) fuel tank of a Delta 2 launch vehicle that landed in Texas, 1997. The vehicle survived re-entry without completely burning up in the atmosphere



# Into Deep Space

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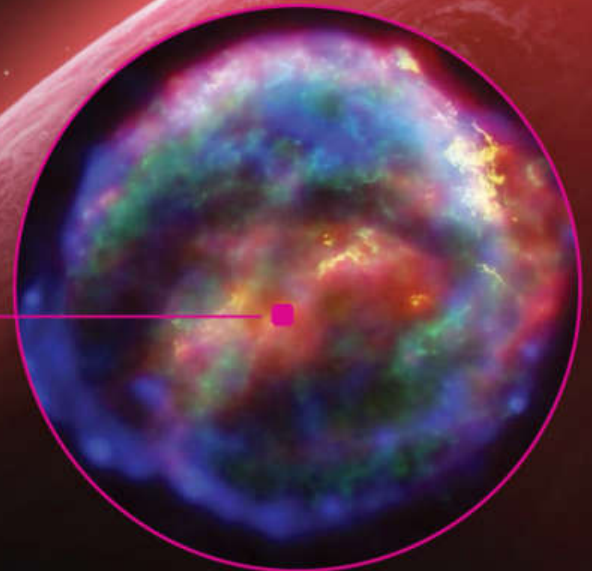
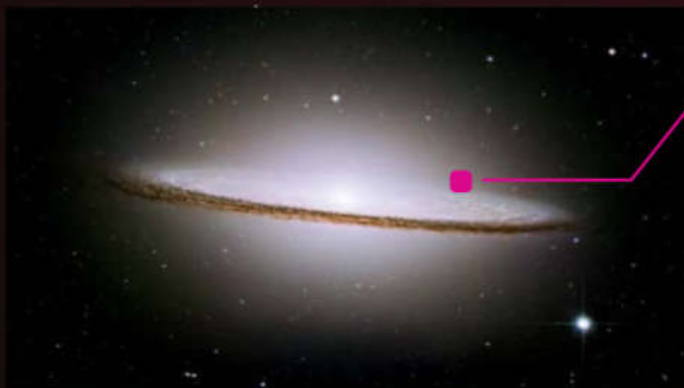
These invisible galaxies were brought to light

## 168 Hypergiant stars

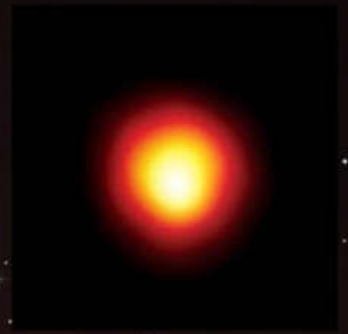
Understand how the stars push the limits of astrophysics

## 164 Sombrero galaxy

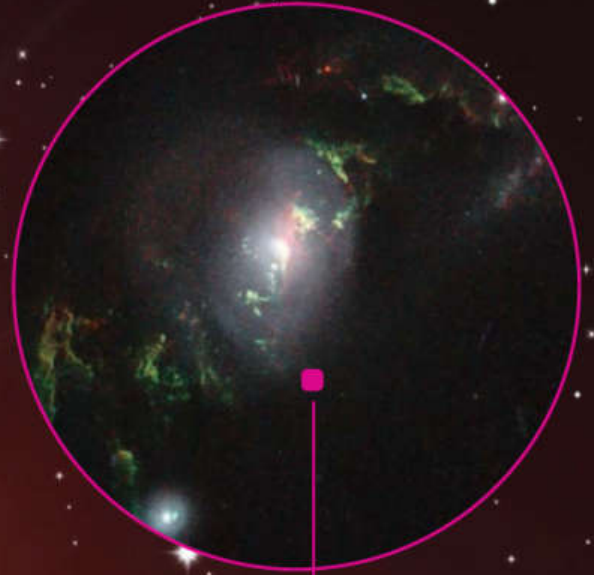
## 136 Supernovas





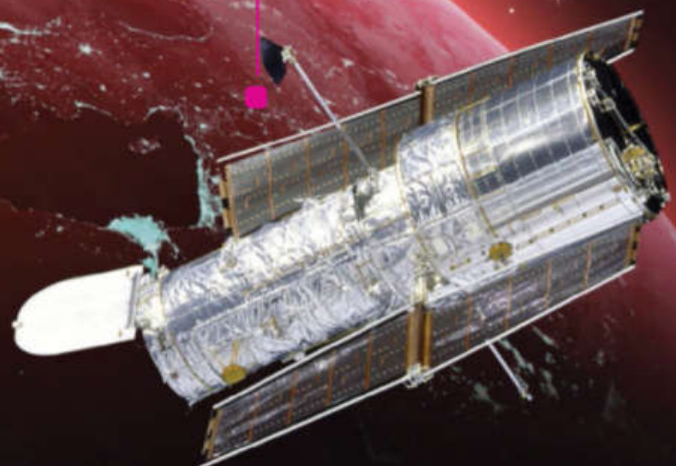


**146**  
Alien  
worlds



**166**  
Galactic  
Ghosts

**168**  
Hypergiant  
stars





# SUPER

The energy of



# NOVAS

## a billion suns

The massive stellar explosions capable of sending cosmic shockwaves across entire galaxies

Stars are large and volatile masses of energy, finely balanced to allow their existence to continue while also emitting large amounts of energy into their surroundings. Their very presence is one of the wonders of the universe, with these giant hot and dense balls of gas able to survive the harsh reality of space. But when the finely-tuned balance of gravity and pressure within a star is altered, something rather remarkable often happens. Try to imagine an explosion more powerful than a billion suns, and you might start to understand how stars can meet their explosive end when they go supernova.

In 185 AD, Chinese astronomers were astounded when a new star appeared in the night sky for eight months. The star appeared from nowhere and was stationary, ruling out the possibility of it being a comet. Although unknown at the time, those Chinese astronomers (and possibly Roman astronomers around the same period as well) unwittingly became the first people to record a supernova, which we know today as SN 185. In 2006, NASA's Chandra and XMM-Newton X-ray observatories imaged a remnant called RCW 86, a vast shell of gas seemingly ejected by SN 185. It might have taken 2,000 years, but we're gradually becoming able to observe and understand these massive events like never before.



When we deal with measures of time in this article, it is worth bearing in mind the limitations of the speed of light. When SN 185 was first observed in 185 AD, those Chinese astronomers were actually observing an event that happened 8,200 years prior, as SN 185 is 8,200 light years away. Of course, when the light finally reaches us we are able to observe the events in their entirety, but it is important to realise that these are cosmic occurrences that happened long in the past, from thousands of years to billions in some instances.

That doesn't take away from the scientific merit of observing them, however. They might be snapshots into the universe's past but they still hold key information into stellar life cycles and the regeneration of the cosmos. In fact, supernovas are thought to be among the most important events in the universe for a number of reasons. Before we tackle that, though, we need to understand the basics of how a supernova works.

At the heart of stars a process called fusion takes place, where light elements such as hydrogen and helium fuse together to form heavier elements, anything from carbon to iron to oxygen. The process of nuclear fusion releases a vast amount of energy in the form of many different types of radiation, including heat and visible light, both of which we directly observe and feel ourselves every day from the Sun. Stars are abundant in both hydrogen and helium, but their supplies are not endless. While it varies from star to star, eventually a star's source of fuel runs out. In most cases the predominant element left at the star's core is iron, which no star is able to fuse. What happens next is simply astounding.

Eventually, so much iron will build up that the star can no longer support its own weight. Until this point, and indeed for the majority of a star's lifetime, the force of gravity pulling the star inwards is delicately balanced by the pressure of the star's gases radiating outwards. Once the fuel is gone, however, this pressure suddenly dissipates. In just a millisecond, the core (which is now rich in iron and more massive than the Sun) collapses in on itself, shrinking in size by up to a thousand times from the size of the Earth to a ball only about 20 kilometres (12 miles) across.

Incredibly, though, the collapse is so quick that the layers of gas surrounding the core don't have time to react. Just a split second later, before these layers have even had a chance to begin collapsing as well, the now ultra-dense iron-rich core explodes with more energy than a quantity of TNT the size of Earth being instantly detonated. The energy output of a supernova is similarly astounding.

In most cases a supernova will shine as bright as 10 billion suns, and it will release  $10^{44}$  joules, which is roughly the total output of the Sun in its entire 10 billion year lifetime. The resultant shockwave can travel at velocities approaching half the speed of light, and it will continue expanding into the surrounding interstellar space for thousands of years. The rate of expansion is such that a supernova's effects can be felt tens or even hundreds of light years away. If you think that all stars meet this same explosive end, however, you'd be wrong.

There are two main types of supernova: Type I, or companion star supernovas, and Type II, or core

collapse supernovas. The former typically occur in stars when their mass exceeds 1.4 solar masses, known as the Chandrasekhar limit, due to the accretion of matter in a binary star system with a white dwarf star, while the latter involve the collapse of stars between eight and 15 solar masses.

Both types are further sub-categorised to denote the particular characteristics of the supernova. The light of Type II-L supernovas steadily decreases after the explosion, whereas Type II-P supernovas emit light much more steadily. Type Ia supernovas involve a white dwarf and a larger star in a binary system, whereas Type Ib and Ic supernovas are more similar to the core collapse scenario, but they will have already lost most of their outer layers before the explosion.

One of the few supernovas to be observed was SN 2008D in the spiral galaxy NGC 2770 back in early 2008. By chance, researchers using NASA's orbiting Swift telescope noticed an increase in X-rays from the star, and immediately alerted eight other ground and space telescopes to the event. The resulting blast lasted just five minutes, but the research will surely last a lifetime. The expansion rate was estimated at 10,000 kilometres (6,000 miles) per second, although one side of the star expanded faster than the other, suggesting that the explosion was off-centred.

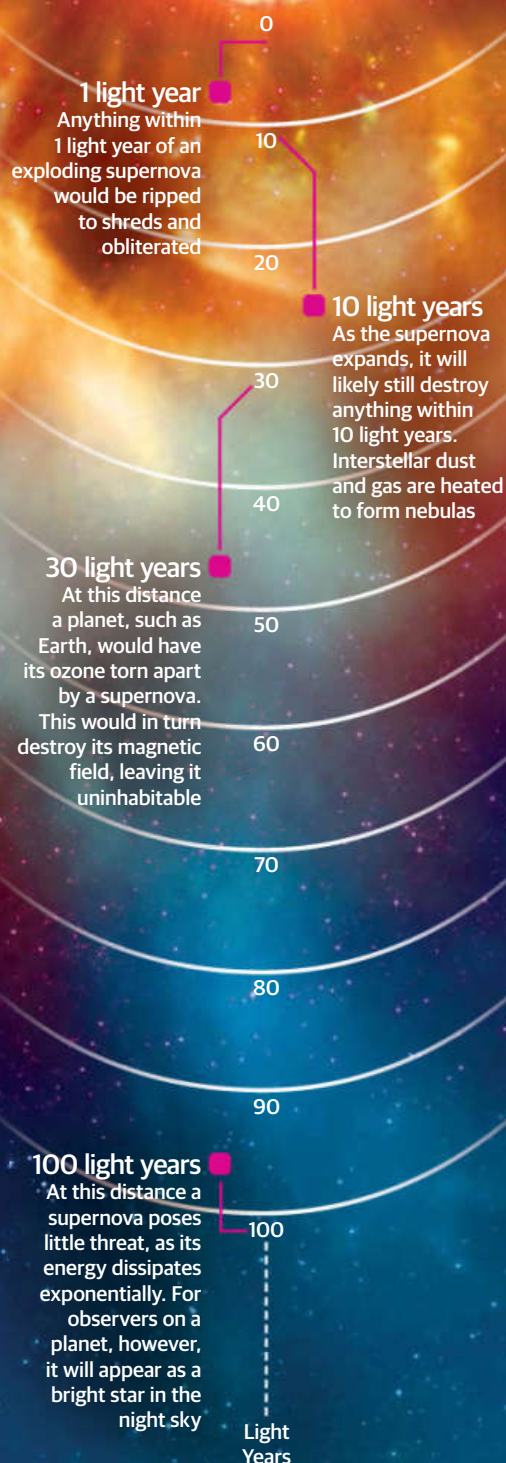
The universe is abundant in hydrogen and helium but not so much in heavier elements such as carbon and oxygen, life-essential elements without which planets like Earth could not become habitable. The only place where these heavier elements are known to be made is in the very heart of stars, where they are stored until the star explodes as a supernova and scatters them into the surrounding space. Without supernovas, these elements would remain locked away, unable to contribute to the formation of metal-rich objects like planets and asteroids. It's very likely that planetary systems, like our own Solar System, were born in this way, from a cloud of dust and gas left behind after a star went supernova.

Another important consequence of supernovas is the formation of new stars. One of the oldest stars



Supernovas often leave behind their dense cores

## Blast radius of an exploding star





# Supernovas and the stellar cycle

## 1. Matter

Material scattered throughout the universe will clump together into clouds of hot dust and gas over time, providing prime locations for stellar and planetary formation

## 2. Formation

Over millions or billions of years, the dust and gas are compressed into high density clouds made of mostly hydrogen where stars and planets begin to form

## 3. Ignition

Nuclear fusion ignites in a star's core and it gradually burns through its hydrogen and helium fuel over millions or billions of years, forming heavier elements at its core in the process

## 4. Supernova

If a star is between about 1.4 and 15 solar masses it will likely explode as a supernova when it runs out of fuel. Most of the heavy elements in the star's core are ejected in the process

## 5. Recycle

The heavier elements expand into the interstellar medium and eventually merge with interstellar material, forming new hot clouds of dust and gas, and the cycle starts again



that we know of is HE 1523-0901, a red giant star 7,500 light years from Earth. It was thought to have formed about 13.2 billion years ago, 500 million years after the estimated beginning of the universe. Clearly this means that most stars that we know of were formed after the Big Bang, in some cases (such as our own Sun) many billions of years after. The only way new stars could have been born was if older stars that survived from the birth of the universe eventually went supernova, releasing their various elements and eventually leading the way to the formation of new stars.

The final major contribution of supernovas to the universe is the continued addition of heavy elements to the interstellar medium. The gradual growth in abundance of these heavier elements, ones that were only found in traces before, has had an odd effect on some stars. Those like our own Sun undergo a somewhat different fusion process to those stars born nearer the start of the universe, as the former are moderated more by the presence of carbon. It is likely that future stars will continue to be altered by the presence of more heavy elements, further altering the fusion process within stars.

So, it's safe to say that supernovas are really quite important, but how do we know so much about them? After all, we've only observed very few, instead normally catching only the aftermath or the resultant remnant. Well, fortunately by observing the aftermath we're able to discern a lot about the explosion itself. For one thing, most Type Ia supernovas seem to undergo very similar final moments. If we see one explode we are able to calculate how far away it is thanks to something known as the "standard candle" method, where all Type Ia explosions explode with pretty much the same magnitude. In addition, using spectroscopy, we can analyse the resultant remnant and, by observing its size and composition, we can work out what the original star might have been like.

Supernovas will continue to be one of the most fascinating and exhilarating events in the universe, providing us with a view into stellar formation and the death of stars. It is thanks to these events that we know so much about the inner composition of stars, and by continuing to study them we will unearth more secrets of the universe. ●

## What is a remnant?

A supernova remnant is the expansion of the blast wave from the supernova as it moves through space, pushing material out along with it that we can observe in different wavelengths from Earth. The expansion rate of a remnant can be up to several thousand kilometres per second, approaching 1% the speed of light, and it may continue for hundreds or thousands of years. Many nebulas we can see from earth are the result of the expansion of supernova remnants, and they can often measure several hundred light years across.

## What happens when a star explodes?

### 1. Fusion

At the core of the star, light elements like hydrogen and helium are converted into heavier elements like iron and carbon

### 2. Mass

When the mass of the core is great enough, usually due to an abundance of iron, the fusion process stops

### 3. Explosion

The star fights the gravitational pull of its core but eventually gives way and explodes

### 4. Off-centred

The explosion of a star is not uniform, with certain parts experiencing a greater force than others



**8. Obliterated**  
In some cases the entire star is obliterated, leaving nothing behind

**7. Remnant**  
At the core of the star where the supernova occurred, there might be a neutron star or black hole left behind

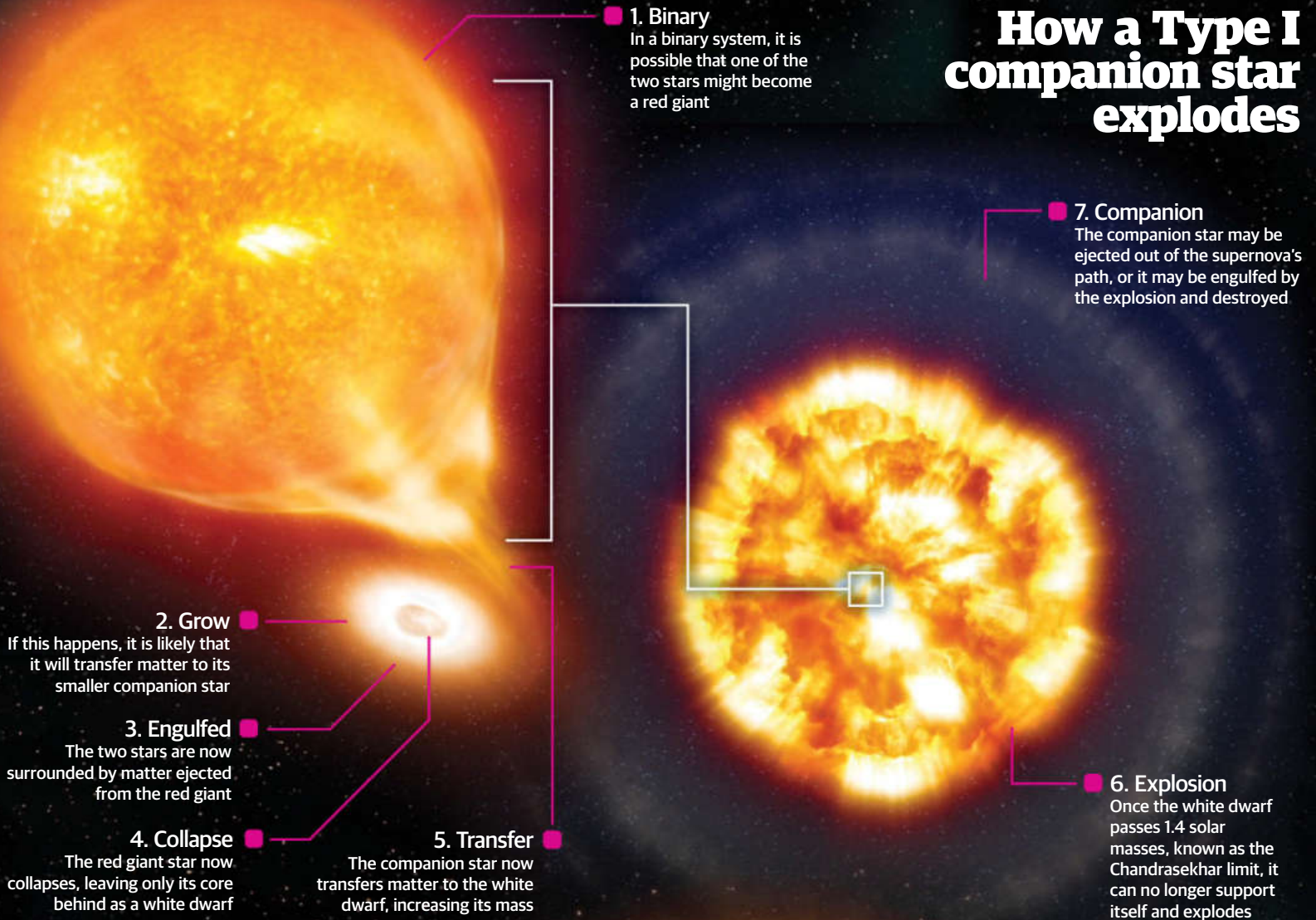
**6. Layers**  
The layers of the star are blown out into space in waves, with their expansion continuing for hundreds or thousands of years

**5. Shape**  
The off-centred explosion is the reason why remnants are often not uniform, instead drifting in vast shapes across space

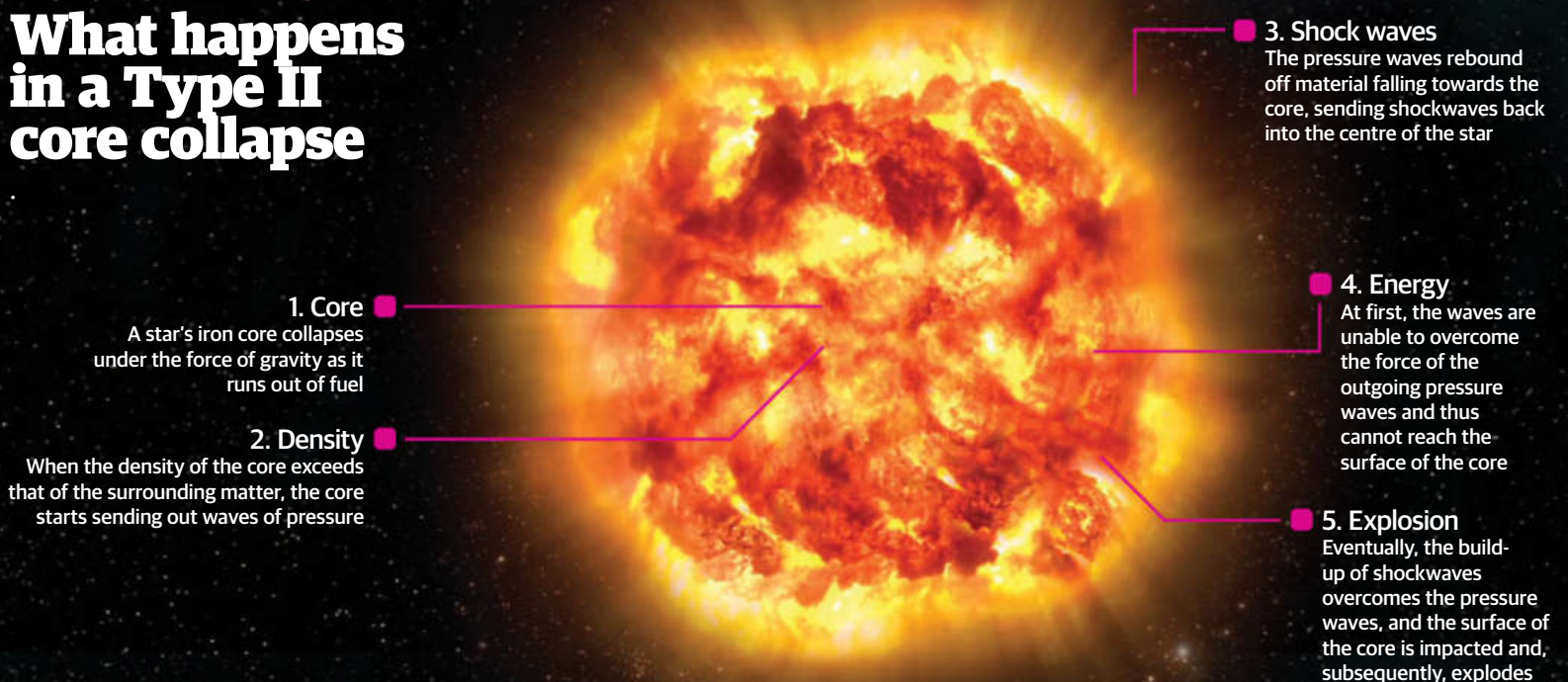
“Using spectroscopy we can analyse the resultant remnant and we can work out what the original star might have been like”



## How a Type I companion star explodes



## What happens in a Type II core collapse





## Most spectacular supernovas

### Crab Nebula

Exploded: 7,500 years ago

Distance: 6,500 light years

This famous supernova remnant has a rapidly rotating star known as the Crab Pulsar at its centre, left behind after the original star exploded. This nebula is now 11 light years across but is still expanding at a rate of 1,500 km (930 miles) per second, 0.5% the speed of light. It is part of the Perseus Arm of the Milky Way Galaxy and the nebula is also referred to as Messier 1 or M1, being the first Messier Object catalogued in 1758. The explosion of the supernova that created this nebula, SN 1054, was recorded around the world in 1054 AD.

### Kepler's Supernova

Exploded: 24,000 years ago

Distance: 20,000 light years

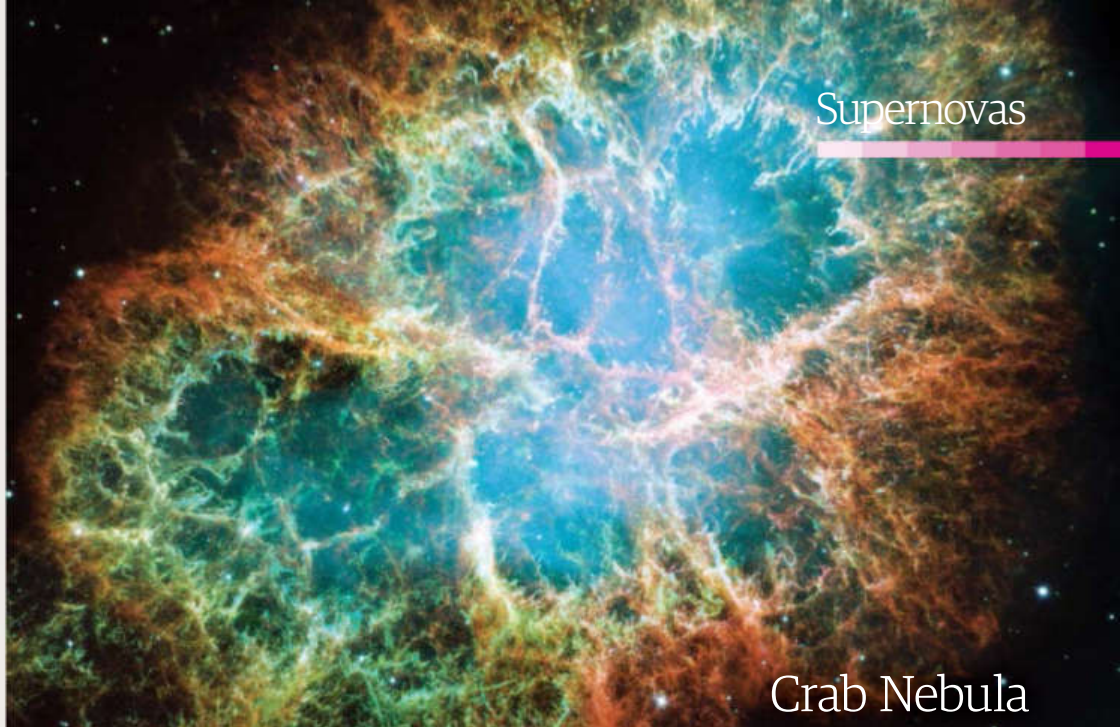
Observed by astronomer Johannes Kepler in October 1604, hence the name, Kepler's Supernova (SN 1604) is the most recent stellar explosion that was visible to the naked eye on Earth, although evidence exists for a Milky Way supernova whose signal would have reached earth around 1868, but was not visible to the unaided human eye. Kepler's Supernova was brighter in the night sky for three weeks than any other star or planet, except for the Sun and Venus, and could even be seen during the day.

### RCW 86

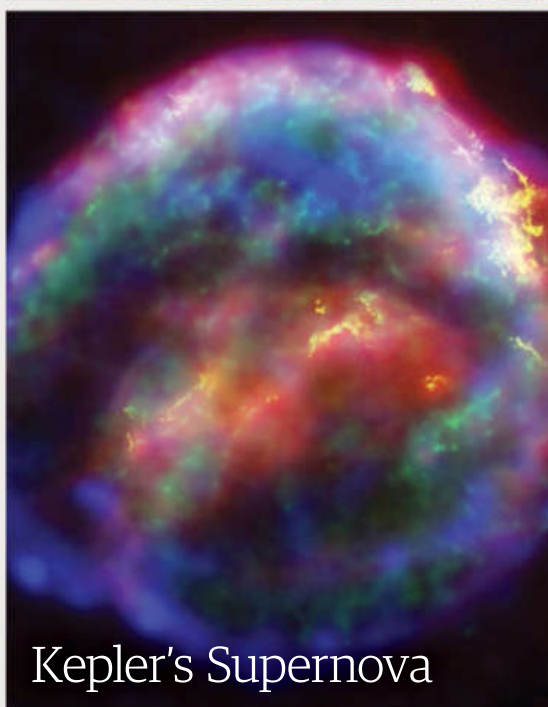
Exploded: 11,000 years ago

Distance: 9,100 light years

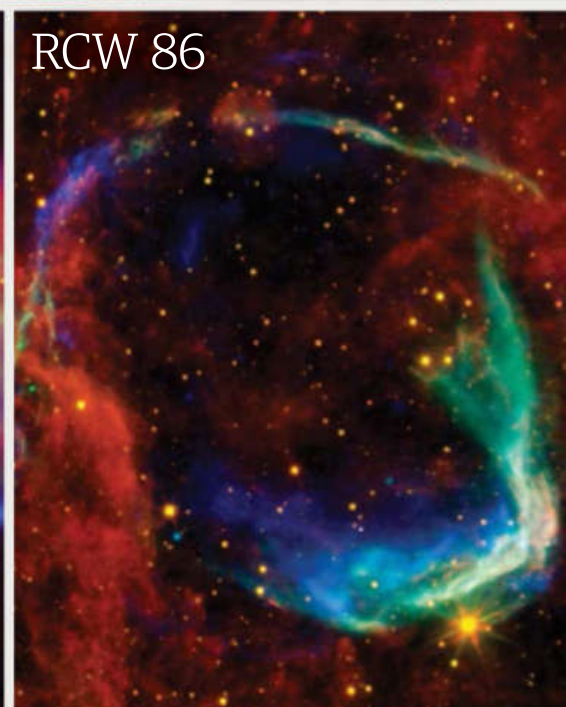
This supernova remnant is thought to be that left behind after star SN 185 blew up in 185 AD. It was recorded by Chinese astronomers and remained visible for some eight weeks. Recent X-ray studies show a good match for this estimated age. As such, RCW 86 is the oldest recorded supernova, and was thought to be a companion star supernova. The remnant is bigger than scientists would expect from such a supernova, suggesting the initial dwarf star created a 'cavity' in space before it exploded into which ejected material could quickly traverse.



Crab Nebula



Kepler's Supernova



RCW 86

## Coming soon to a galaxy near you...

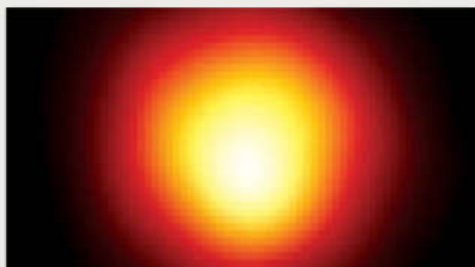


### IK Pegasi

Will explode: 5 million years from now

Distance: 150 light years

IK Pegasi A is expected to evolve into a red giant, which will transfer matter to the smaller IK Pegasi B white dwarf star and cause it to explode in a Type Ia supernova. IK Pegasi is moving away, so while it is currently the closest star to us that can go supernova, when it does in a few million years it will no longer be.



### Betelgeuse

Will explode: 0 to 1 million years from now

Distance: 640 light years

Currently in the later stages of its life, it is expected to explode as a Type II supernova within the next million years, although it could explode at any minute. The star is a red supergiant and is less than ten million years old, a minuscule amount in astronomical terms, and thus it has passed through its life rapidly.



### Antares

Will explode: 0 to 1 million years from now

Distance: 550 light years

The red supergiant Antares has a companion star, Antares B, that is thought will contribute to a Type Ia supernova event in the coming years. However, the exact timing of the supernova is unknown. Antares is more than 880 times bigger than our Sun and thus the explosion is expected to be quite an event.



# Behemoth galaxy

At the heart of the giant Perseus cluster lies a monster of a galaxy

It seems appropriate that one of the most massive known objects in the universe, the Perseus galactic cluster, should also be home to a particularly huge galaxy at its centre. The giant elliptical NGC 1275 is 230 million light years away in the constellation of Perseus and actually consists of two galaxies - one a huge elliptical and the other a small spiral - in what's known as a high-velocity system.

These galaxies seem set to collide and are moving towards each other at 3,000 kilometres (1,864 miles) per second. This Hubble Space Telescope image shows filaments of cool, mainly hydrogen

gas surrounded by gas measuring up to 55 million degrees Celsius (100 million degrees Fahrenheit) in the cluster, which emits strong X-rays.

The Perseus cluster has recently come under the spotlight of astronomers because it's the source of a particular X-ray signal that couldn't have come from ordinary matter. It's thought that an exotic particle called a sterile neutrino, which is related to dark matter, could be responsible. Study of the Perseus cluster, and other massive objects in the universe like it, is giving scientists a better idea of the nature of dark matter. ■



# Behemoth galaxy

Filaments feed out of the giant elliptical galaxy NGC 1275 in searing-hot, X-ray-emitting gas in the Perseus cluster





# Tour the Alien Worlds

The distant Gliese system could hold potentially habitable worlds.  
Discover what life could be like on these unknown planets

Only 20 light years away from Earth lies a world that, if it were confirmed, looks pretty similar to our own. Gliese 581 g (as it is known by astronomers) is only three to four times the mass of Earth. It's tricky to say if it exists for sure because of the different measurement techniques used by various astronomers, but the possibilities are tantalising.

Astronomers using the WM Keck Observatory in Hawaii spotted evidence of the planet in 2010. It's thought to be a rocky planet, just like Earth, it probably has an atmosphere and, most importantly, it's in the 'Goldilocks Zone' around a star. This is the zone where temperatures are not too hot and not too cold but 'just right' to support life.

"This is a really exciting system," says Lisa Kaltenegger, an astrophysicist at Harvard University. "If it had water, it would be actually liquid on the surface. It's the first time we've been able to peer across space and detect a possible planet that would be similar to our own."

Even if 581 g turns out to be a false finding, there is even hope that another planet in the same system – 581 d – could support life, if it had a layer of carbon dioxide protecting water on its surface. This makes the entire star's solar system a fascinating target for astronomers.

Planet G of the Gliese 581 system is one of several planets orbiting the red dwarf star. Gliese 581 is a small star only 20 light years away from

Earth. Because the star is a red dwarf, it gives off less heat and light than our Sun, which means its Goldilocks Zone is much closer to the star than the one in which the Earth resides in our Solar System.

Gliese 581's known planets hug the star very closely and the furthest planet from the star, Gliese 581 f, orbits at about the same distance as the planet Venus is from our Sun. (It should be emphasised that Gliese 581 f is not recognised by all astronomers yet.) The rest of Gliese 581's planets are closer to the star than Mercury's orbit from the Sun.

According to Kaltenegger, who splits her research time between Harvard and Germany's famous Max Planck Institute for Astronomy, Gliese

581 has two potential planets that lie around the habitable area. Planet G is the best candidate, if it exists, and Planet D lies just on the outer edge of the zone. But Kaltenegger says it's best not to get too excited yet. "We have great targets, but we don't know if (they) can support life," she says, adding that the next step is to find a way to use telescopes to peer closer at these planets' atmospheres.

Kaltenegger is keen to note that not everyone is in agreement about Planet G's existence. Although announced with great fanfare by NASA and related astronomers in 2010, the way the astronomers detected the planet has not been reliably replicated yet, at least as far as Kaltenegger sees it. Astronomers at the University of



California, Santa Cruz used 11 years of telescope observations at Keck to find Gliese 581 g, using a spectrometer that watched over its parent star. The spectrometer was used to measure the star's radial velocity, or its movement relative to Earth's line of sight. If a star has planets that are large enough and close enough, the planets tug at the star's gravity ever so slightly. With multiple planets orbiting the star, the star begins to wobble.

Planet hunters have become so sophisticated in their techniques that they can take a star's wobble and infer how many planets are orbiting it, as well as the masses of those planets.

"Keck's long-term observations of the wobble of nearby stars enabled the detection of this multi-planetary system," stated Mario Perez, a programme scientist at the Keck Observatory, in the news release concerning Planet G's discovery.

However, a team from Geneva (led by Francesco Pepe) analysed over six years of data concerning Gliese 581 using a spectrometer at La Silla Telescope in Chile.

Also in 2010, they announced at an exoplanet conference in Italy that they had not found any evidence of Gliese 581 g. That said, the precision of the instrument is not sharp enough to definitively rule Gliese 581 g out.

Subsequent teams of astronomers have been arguing back and forth for years now whether 581 g is actually there, or if the wobble detected around the star needs to have a new model made to explain it. It will take more observations of the star before anyone can say for sure what lies within that system and a definitive answer may not come for years or even decades.

The planet 581 d lies slightly further from the star than 581 g. It's also a bit larger than our world at between five and seven Earth masses. In a science paper posted on Arxiv, Kaltenegger's team calls it a "potentially habitable rocky Super-Earth".

Also, it's a little on the cold side when it comes to habitability, but some astronomers believe a thick layer of carbon dioxide in the atmosphere could shield 581 d from the cold. Of course, that's assuming the planet has an Earth-like composition, which is not a guarantee.

The theory, as Kaltenegger explains it, is carbon dioxide gets emitted from volcanoes on 581 d's surface. In the early days of the planet's formation, rain would wash the carbon dioxide out of the atmosphere so it couldn't accumulate. But as the planet cooled,

**"It's the first time we've been able to peer across space and detect a possible planet that would be similar to our own"**

**Lisa Kaltenegger, astrophysicist at Harvard University**

that rain would turn into snow. Snow doesn't have the same power to wash carbon dioxide away, so the gas would accumulate in the atmosphere.

"It builds up in the atmosphere, increases your greenhouse effect, and warms until you have water," Kaltenegger says. This makes it easier to believe that life would exist there.

Even if planets 581 g and 581 d were vegetated, though, it would look a lot different from Earth. The cool light from Gliese 581 would barely be enough for plants to photosynthesise, so the plants would not be green like you would see here on Earth. The colour would take too much energy. Additionally, the light would look different than what we are used to on Earth, as a red dwarf mostly gives off its energy in red light.

In 2012, Australian astronomers - who are involved in the search for extraterrestrial life - trained their cosmic ears at Gliese 581. They linked together three radio telescopes in Australia in an attempt to hear radio signals coming from the system.

The astronomers didn't hear anything, but that's not to say that life is absent from the system. Gliese 581 d and 581 g are both in or within the habitable zones, and it will take many years of future study to learn more about their climatic conditions.

In the meantime, Gliese 581's system provides plenty for astronomers to study. There are up to six planets orbiting the star, each with a unique environment worth closer study.

While 581 f and 581 g are not universally accepted, there are four others that are receiving further attention from astronomers.

581 e is the closest to the star and would appear as a big Mercury if you were standing on the surface. It's about double the mass of Earth.

Next out is 581 b, which would be a gas planet - at 15.6 Earth masses - that is approaching the size of Jupiter.

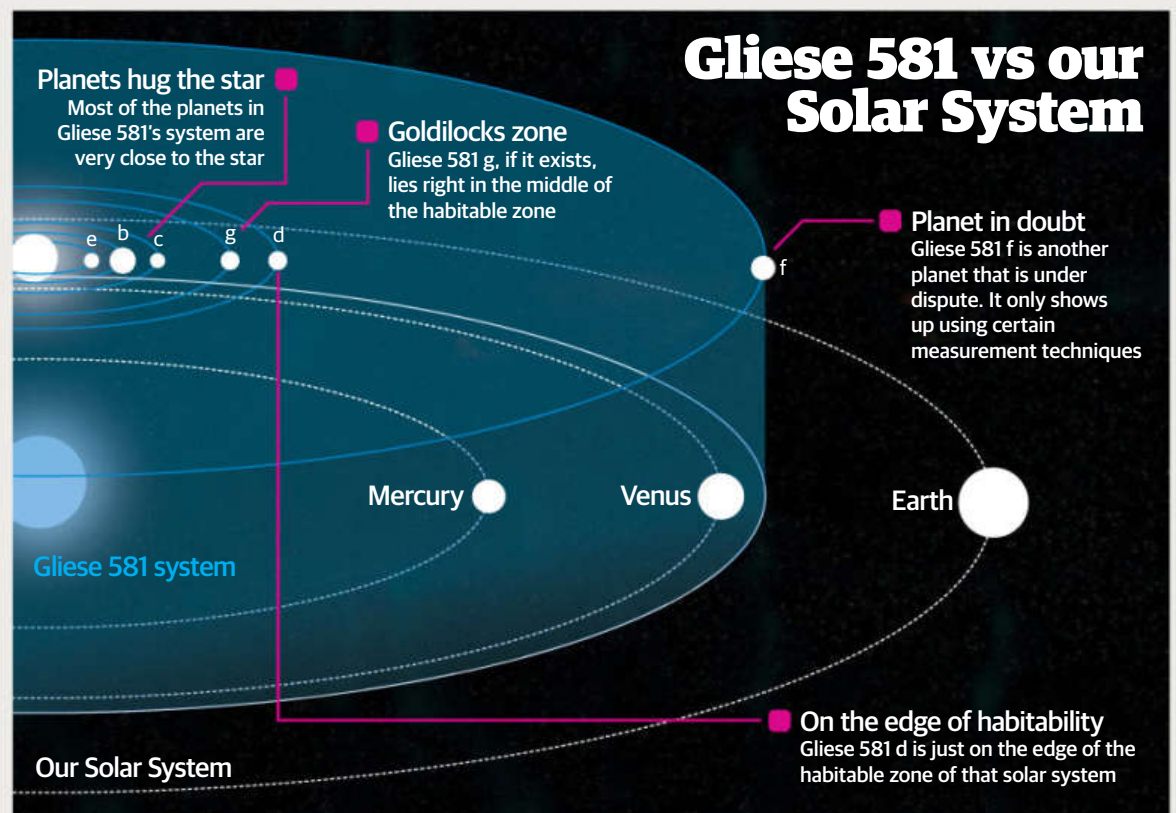
Third in the system, and before 581 g and 581 d, is 581 c. Planet C, more than five times Earth's mass, would actually look a lot like Venus, in that any water would have evaporated from

the surface and it would probably be covered in a thick atmosphere if it had any available to it.

Kaltenegger says we are just at the beginning of understanding the Gliese 581 system. "Planets are so hard to find because they look tiny near the star," she explains. "(What's) exciting is we're finding more and more planets with this simple wobble method... we can even find the small ones that don't have much mass or are not very big."

Surely as telescopic observations and computer technology continue to improve, we'll have the opportunity to spot more candidates for supporting life like Gliese 581 d or 581 g. We'll be able to more precisely predict how planets move about their stars, and also be able to infer the composition of their atmospheres.

Learning more about the way other solar systems formed brings us to a better understanding of what happened here on Earth. Gliese 581's system, even though it is 20 light years away from us, will therefore teach us more about our own home. ●





### Gliese 581 e

"The Gliese 581 system is intriguing because it hosts planets that could be like big Earths and also planets that are so different from the ones we know in our Solar System," said Kaltenegger. Gliese 581 e is estimated to have a mass about double that of Earth, and "at this mass we can speculate that it could resemble a hot super-Mercury on a three-day orbit." It is extremely close to the Gliese star and therefore likely to be very hot.

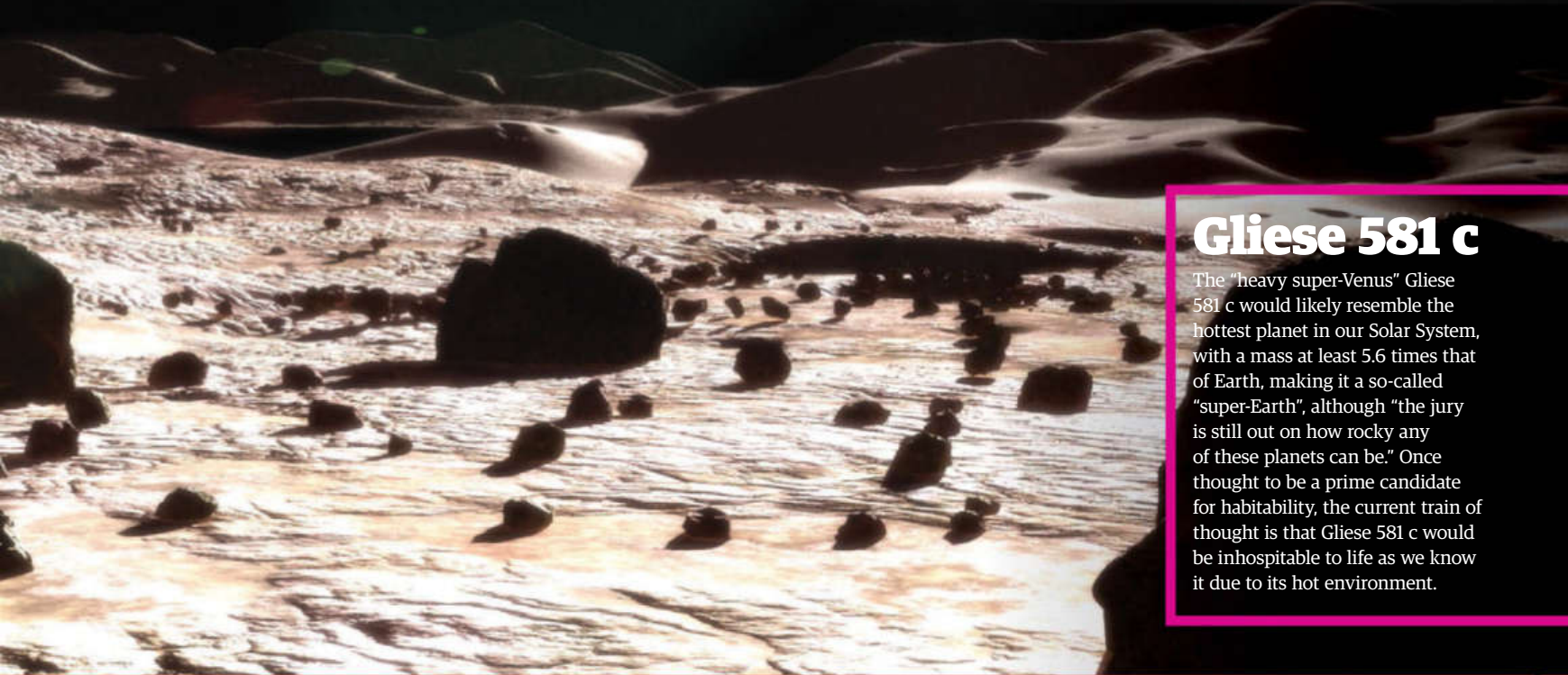


### Gliese 581 b

"Without more information we can only speculate what these planets could be like - until we get a bigger telescope that can explore their atmospheres and tell us what they are like," said Kaltenegger. This is especially true for Gliese 581 b. "All of the planets in the Gliese system are heavier than Earth." The heaviest of those is Gliese 581 b at almost 16 Earth masses, which could be a "hot mini-Neptune" or a Venus-like world.



"The Gliese 581 system is intriguing because it hosts planets that could be like big Earths"



## Gliese 581 c

The "heavy super-Venus" Gliese 581 c would likely resemble the hottest planet in our Solar System, with a mass at least 5.6 times that of Earth, making it a so-called "super-Earth", although "the jury is still out on how rocky any of these planets can be." Once thought to be a prime candidate for habitability, the current train of thought is that Gliese 581 c would be inhospitable to life as we know it due to its hot environment.



## Gliese 581 d

This is probably the most Earth-like of these planets, found in the system's habitable zone. "If Gliese 581 d is really a rocky planet that could have developed life," says Kaltenegger, "then such life would be used to a red sun in its sky and may have very different dark vegetation - if it developed at all. It would be a heavy, cooler, super-Earth with about double Earth's gravity, a workout for us were we ever to set foot on the surface."



# Deepest ever view of the universe

Hubble scientists have recorded the history of galaxies in this one image, from soon after the first galaxies were formed to their huge contemporaries

You are looking at one of the most extraordinary views of the universe ever created. It's called the eXtreme Deep Field or XDF and was assembled by combining ten years of NASA Hubble Space Telescope photographs taken of a patch of sky at the centre of the original Hubble Ultra Deep Field. This was an image of a small area of space in the constellation Fornax, created using Hubble Space Telescope data from 2003 and 2004. The new full-colour XDF image shown here uses the infra-red spectrum to reach much fainter galaxies, enabling new studies of the earliest galaxies in the universe. This has been achieved by incorporating well over 2,000 separate exposures from Hubble's two main cameras - the Advanced Camera for Surveys, which has been operational since 2002, and the Wide Field

Camera 3, which was installed during the very last service of the telescope performed in 2009.

The image represents a valuable astronomical tool which will be used by scientists for many years, showing more than 5,000 galaxies, among which is a candidate for the most distant galaxy yet discovered. Should this be confirmed, the galaxy known as UDFj-39546284 is being seen just 460 million years after the Big Bang. In fact, most of the galaxies visible in the XDF are seen when they are in their infancy, often colliding and merging together and these images can be followed up by the other, more powerful telescopes of the future such as the James Webb Space Telescope, which should be operational by 2018 and offer even deeper views into the history of the universe. ■



# Deepest ever view of the universe

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This image was created from over  
2,000 separate exposures captured  
by the Hubble Space Telescope





# Bubble Nebula

What's behind this interstellar phenomenon floating in the far reaches of space?

11,000 light years away in the Cassiopeia constellation can be found this fascinating nebula that at first glance bears resemblance to a bubble. Also known as NGC 7635, the ten-light-year-wide Bubble Nebula is an emission nebula that was formed from a young and hot star at its centre.

It was first discovered in 1787 by William Herschel, and since then it has been the subject of detailed observations. Near the centre of the bubble can be seen the bright star BD+60°2522, several hundred thousand times more luminous and nearly 50 times more massive than the Sun. This star

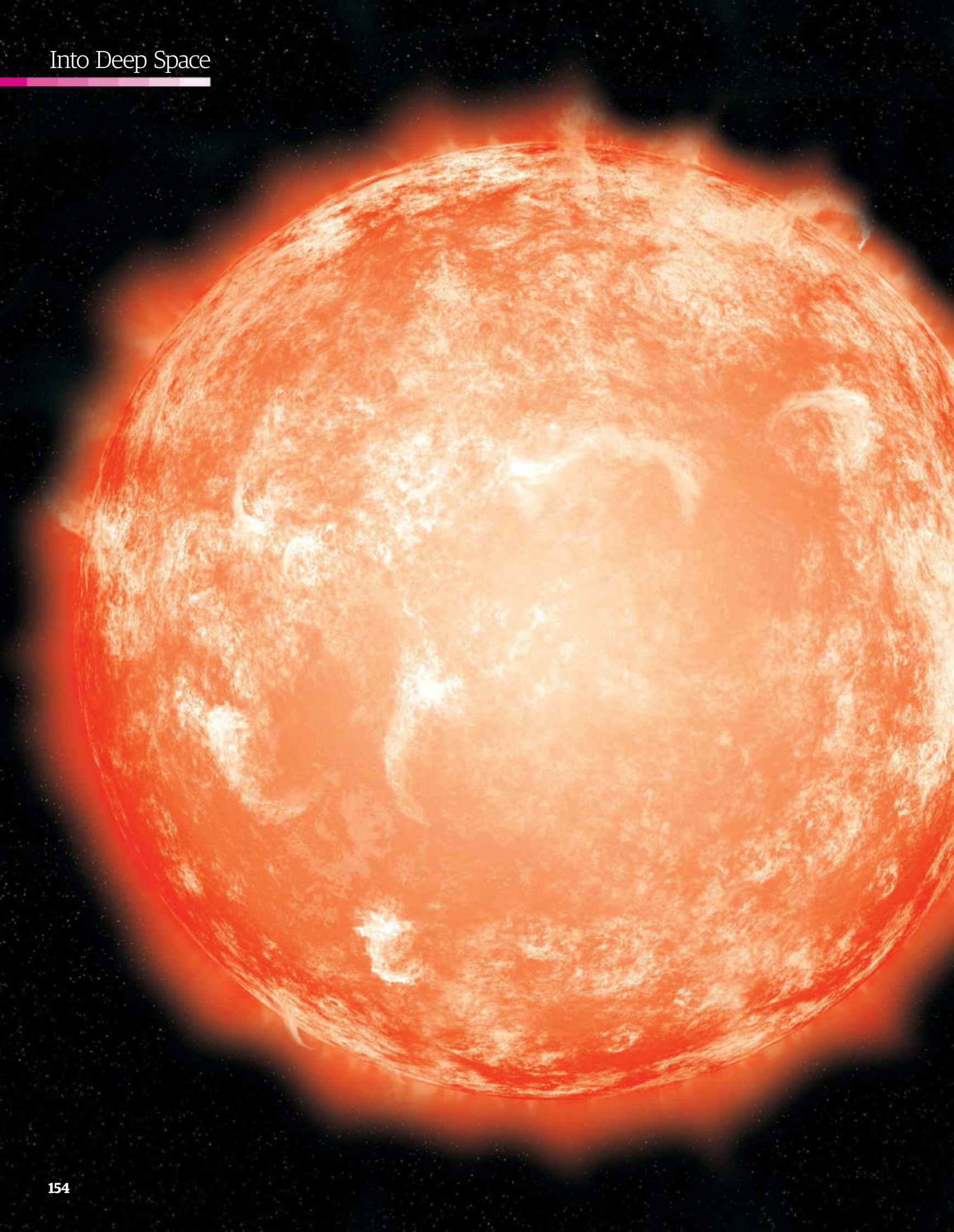
blasted out intense radiation and a fierce stellar wind, which in turn interacted with denser material in a surrounding molecular cloud and formed the Bubble Nebula.

The nebula itself is one of three shells of gas originating from BD+60°2522. This star also ionises the shell by continuously emitting energetic radiation, which causes it to shine. Aside from the interesting shells that glow from the interaction with its central star, some wisps near the bottom right of the image are the remnants of a supernova explosion thousands of years old. ■













# All About... PROXIMA CENTAURI

This tiny star has captured our interest in a big way as it's the closest one to Earth after our own Sun



Red dwarfs are the most common type of star in our galaxy, but they're impossible to observe from the Earth with the naked eye because they're the dimmest stars. They're also very small and relatively cool due to their low mass. The red dwarf Proxima Centauri is among the smallest and dimmest, but it has the special significance of being the closest star to us other than the Sun.

Proxima Centauri is approximately 4.24 light years (268,000 AU) away, located in the Centaurus constellation. The star is estimated to remain the closest star to ours for another 30,000 years or so, at which point the star Ross 248 in the Andromeda

constellation will come closer (it's currently about 10.3 light years away).

Proxima Centauri is located about 15,000 AU from the next-closest star, the binary system Alpha Centauri. This relative closeness is how Proxima came to be discovered. In 1915, Scottish-South African astronomer Robert Innes observed a star that had the same proper motion - the apparent change of a star's position on the celestial sphere - as Alpha Centauri, which had been first observed in 1689. Depending on who you ask, Proxima is either a companion to Alpha Centauri or a third star in the system.

Since its discovery, Proxima has been closely observed. Because it's a

red dwarf, it will be around for much longer than our Sun - at least four trillion more years - thanks to its slow consumption of fuel. And unlike the Sun, Proxima will completely use up its hydrogen during the fusion process. Satellite X-ray telescopes have provided crucial information about its activities. The Einstein Observatory, an X-ray telescope that orbited the Earth from 1978 to 1982, took the first X-ray images of the star and recorded a solar flare - flashes of brightness and heat caused by magnetic activity. This confirmed astronomer Howard Shapley's announcement in 1951 that Proxima Centauri was a flare star. The European Space Agency's

European X-ray Observatory Satellite (EXOSAT), German ROSAT, and the Japan Aerospace Exploration Agency's Advanced Satellite for Cosmology and Astrophysics (ASCA) have all observed numerous solar flares on Proxima.

Land-based telescopes have also given us data about Proxima. Operated by the European Southern Observatory, the Very Large Telescope (VLT) helped to determine Proxima's distance and size. The star has a mass about one-eighth that of the Sun's, but it's about 40 times denser. Proxima's corona, or plasma 'atmosphere' extending into space beyond the surface, can actually be hotter than that of the Sun - 3.5 million Kelvin as opposed to 2 million Kelvin. On average, its overall temperature is about 3,000 Kelvin. Observations of Proxima's chromosphere indicate that it has a rotation period of about 31 days.

Although the closeness of Proxima Centauri has made for plenty of observation, there are\* still some burning questions. Are there any planets orbiting the star? And if so, are they habitable? The Hubble Space Telescope hinted at the possibility of a planet near Proxima Centauri during observations in 1998, but no further evidence has appeared upon subsequent imaging. Proxima was to have been a target of the Space Interferometry Mission (SIM), a NASA space telescope mission that ultimately got cancelled. The star's closeness continues to make it a promising destination for both observation and actual interstellar travel, and eventually we'll get a better look at our neighbouring star. ●

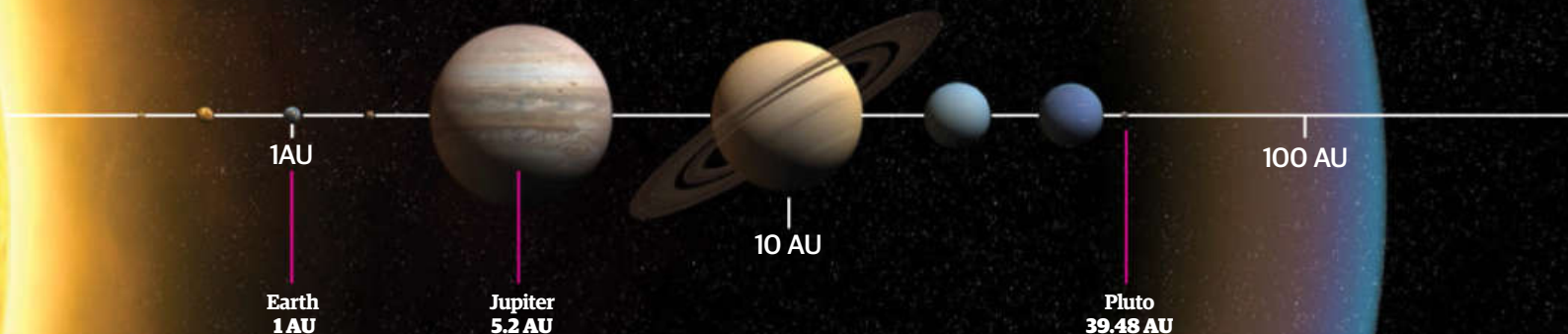
## Centaurus

The constellation Centaurus takes up about 1,060 square degrees and has 281 stars that are visible to the naked eye - more than any other constellation.

Alpha Centauri is the constellation's most notable feature, but there's also Beta Centauri, the tenth-brightest star in the sky that's actually a binary star system. Alpha and Beta Centauri are used together as pointers to Crux (also known as the Southern Cross), a distinctive constellation used by navigators to determine direction. Aside from the stars, Centaurus is also known for its deep sky objects, such as planetary nebulas, star clusters and galaxies. Omega Centauri, a globular star cluster, is the largest and brightest one orbiting the Milky Way and contains several million stars. The galaxy Centaurus A is one of the closest active galaxies to Earth, and has a supermassive black hole at its centre.

## Distance to Proxima Centauri

It may be the closest star after our Sun, but Proxima Centauri is still a very long way from the Earth





## Comparing orbits

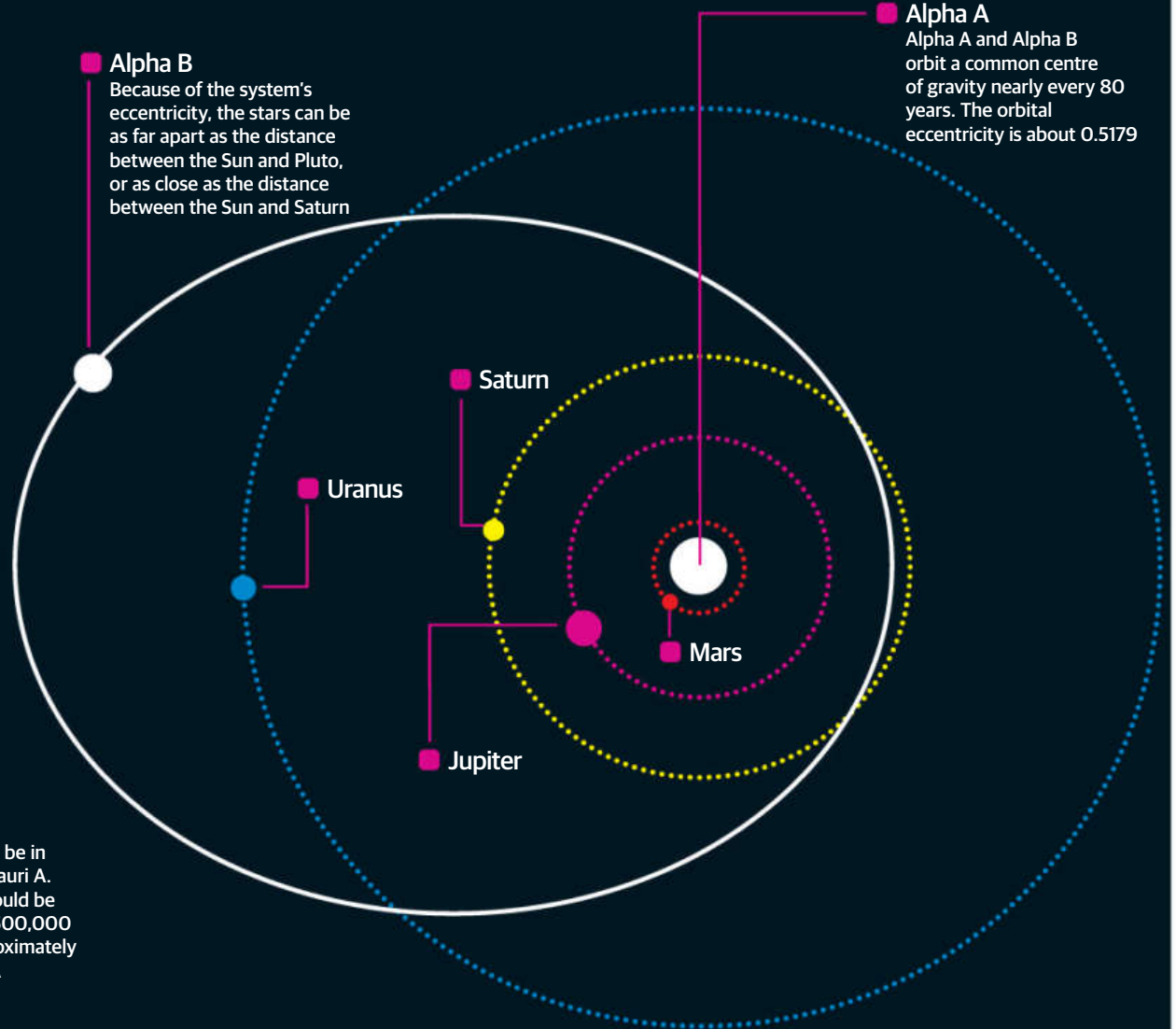
The orbits of Alpha Centauri A and B are larger than those of Mars, Jupiter, and Saturn, but smaller than that of Uranus. There could be a gravitational association between Proxima and the other two stars. If this is true, then Proxima is probably at its furthest point in its orbit right now. But it could also be on a hyperbolic trajectory - a special kind of orbit with an eccentricity greater than 1 - with respect to Alpha Centauri AB. This means that in theory, Proxima could eventually leave the system completely.

### Alpha B

Because of the system's eccentricity, the stars can be as far apart as the distance between the Sun and Pluto, or as close as the distance between the Sun and Saturn.

### Alpha A

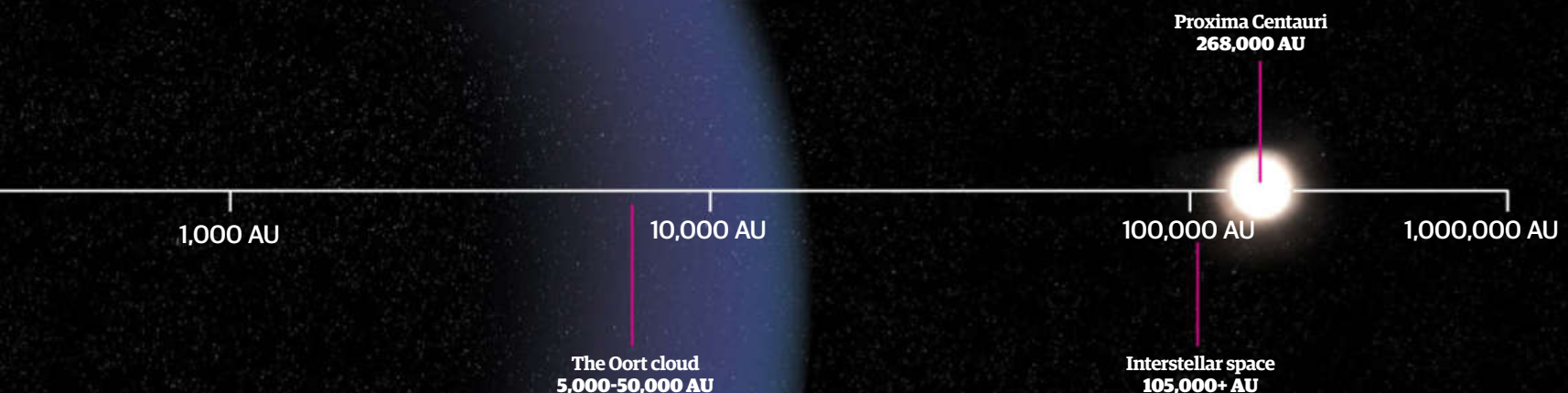
Alpha A and Alpha B orbit a common centre of gravity nearly every 80 years. The orbital eccentricity is about 0.5179.



### Proxima

Proxima may or may not be in orbit around Alpha Centauri A. If so, its orbital period could be between 100,000 and 500,000 years or more. It is approximately 15,000 AU from Alpha A.

1 AU = 150 million kilometres (93 million miles)





# Proxima: inside and out

The closest star to our Solar System is also one of the dimmest and smallest red dwarfs

Proxima Centauri isn't just a red dwarf; it's on the lower end of range for late-type M-class stars with a mass of just 0.123 that of the Sun. They have dense, opaque interiors. Because of this, late-type red dwarfs have no radiative zone - an area outside the core where energy is transferred via radiation present in other types of stars. Instead, both the core and the outer layer, or envelope, are convective. Energy and hydrogen circulate freely. These types of red dwarfs continue to fuse hydrogen into helium in their cores until it's depleted. In contrast, the Sun

will only use up about ten per cent of its hydrogen supply before it leaves the main sequence and goes into a red giant phase.

Compared to larger, more massive stars, the fusion process in red dwarfs is incredibly slow. As a result, the estimated life span of red dwarfs is longer than the age of the universe. The lower the mass of the star, the longer its lifetime, so Proxima's estimated life span is approximately 4 trillion years. As the hydrogen fuel is depleted, the core will contract and it will become a blue dwarf as

its temperature rises to up to 8,200 degrees Celsius (14,800 degrees Fahrenheit) and its luminosity increases, giving it a blue appearance. Once the fuel is gone, Proxima Centauri will become a stellar remnant - first a white dwarf, and then a black dwarf as it no longer emits heat or light. Due to their lengthy life span, the life cycle of a red dwarf is theoretical.

Proxima Centauri is also one of the most active flare stars ever observed, generating X-ray emissions similar to those that come from the Sun. This means that on occasion it can suddenly have flashes of intense brightness. Proxima Centauri's flares are a release from its magnetic field, generated by the convection in the star's interior.

Some scientists have speculated that there is a habitable zone around Proxima Centauri, which would theoretically be a range of about 3.4 million to 8 million kilometres (2 million and 5 million miles) from the star, with an orbital period between 3.6 and 14 days. Red dwarfs emit very little light, and any planet in this zone would probably be tidally locked to the star - with one side remaining in perpetual darkness. This means that there may just be a small region on the planet that is actually habitable, or there would need to be a very thick atmosphere to keep the 'dark' side's temperatures up. In addition, a planet orbiting Proxima Centauri would need to have a strong magnetic field to counteract the effects of the star's flares on its atmosphere.

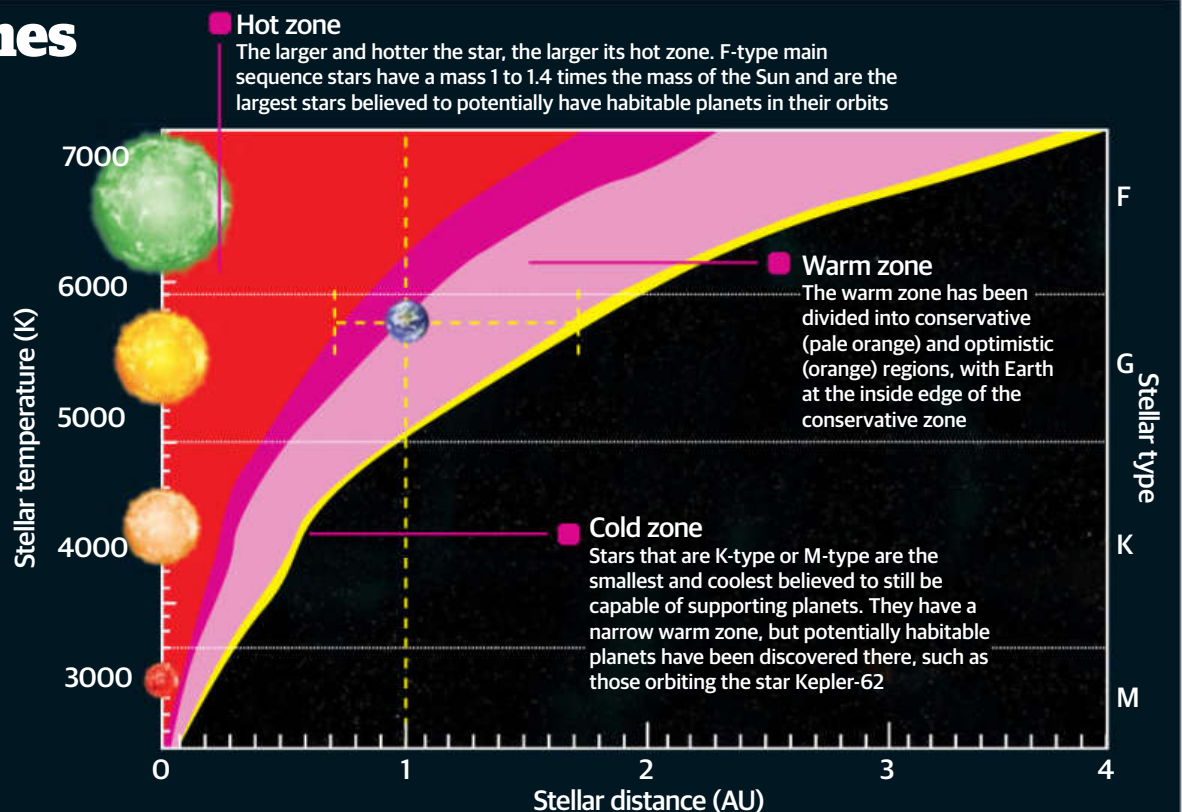
Other potential challenges include weather and winds, both of which may be harsh; and photosynthesis, which could be a very different process since red dwarfs emit most of their radiation in infrared light instead of visible light. One thing that red dwarfs have going for them is their long life; perhaps even if there isn't a habitable zone around Proxima Centauri now, there could be in the future. During the blue dwarf phase the star will be hotter and brighter, possibly allowing for previously uninhabitable planets to become habitable. ●

"It's one of the most active flare stars ever observed"

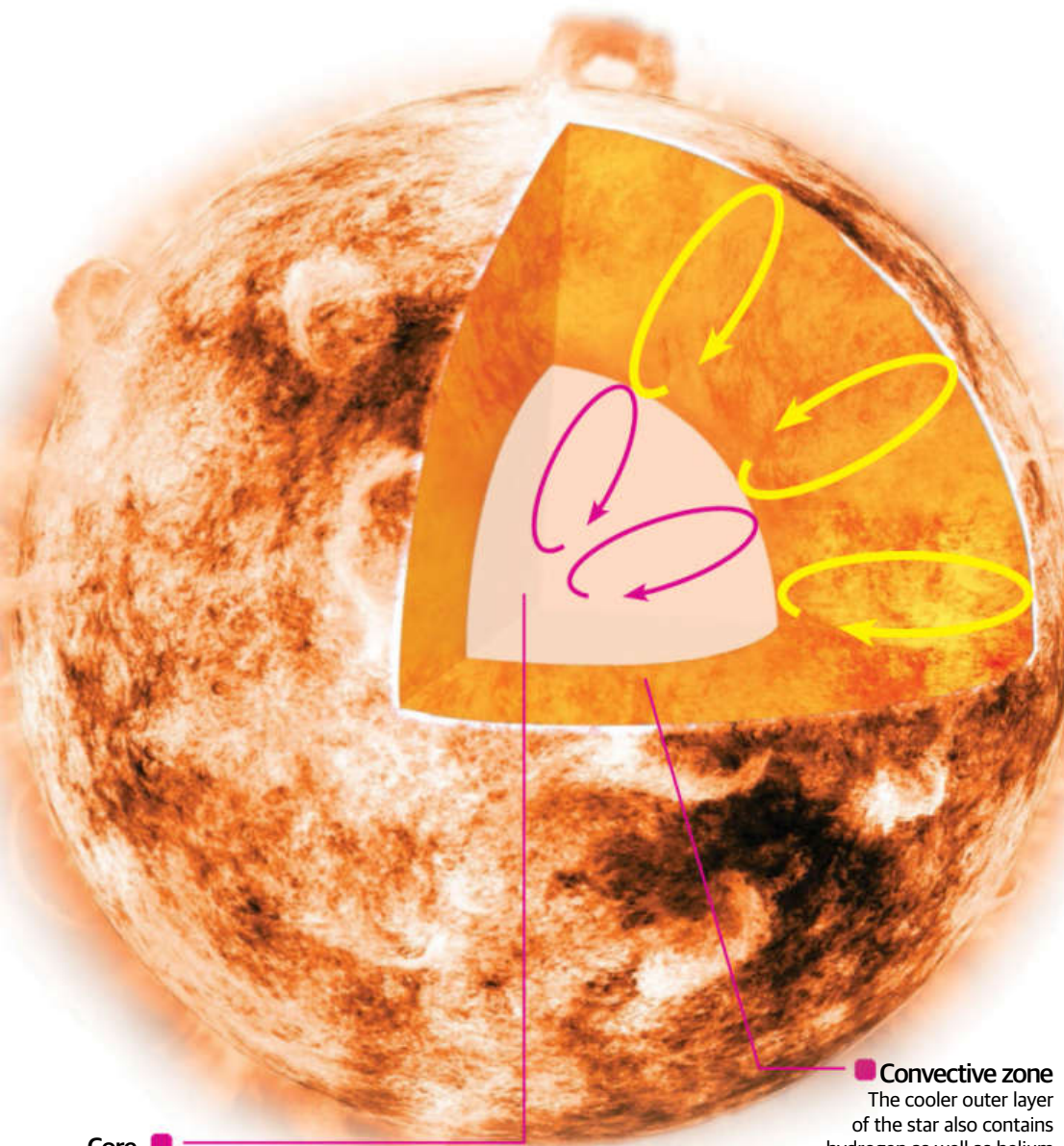
## Habitable zones

The habitable zone comprises areas around stars where life is theoretically possible on the orbiting planets. It is sometimes known as the circumstellar habitable zone, or the Goldilocks Zone because the circumstances are 'just right' - neither too hot nor too cold - for liquid water to be present on the planet's surface. In addition to temperature, there must also be adequate atmospheric pressure. While this seems simple enough, defining parameters for a habitable zone can be challenging. For our Solar System, estimates range from an inner edge of 108 million km (67 million miles) to an outer edge of 448 million km (278 million miles).

As for other solar systems, estimates for the number of habitable planets vary widely - from 500 million to over 150 billion. Some scientists point out that basing the criteria on our own biosphere amounts to carbon chauvinism - the assumption that all extraterrestrial life is carbon-based like life on Earth.







**Core** ■ Because red dwarf stars have a low mass, they are entirely convective (without the radiative zone of other stars). Hydrogen fusion takes place within the core and energy moves via circular currents to the outer envelope

■ **Convective zone**  
The cooler outer layer of the star also contains hydrogen as well as helium (generated as a result of the fusion process). The hydrogen circulates back to the core, where fusion continues for the lengthy main sequence of the star

## Proxima Centauri in numbers

Quick facts and figures about our nearest stellar neighbour

6800

Proxima Centauri is around 6,800 times further from the Sun than Pluto

4 trillion years

*Red dwarf stars like Proxima Centauri can last this long because they burn fuel at a slower rate*

0.0017

Proxima's total luminosity over all wavelengths is 0.17% that of the Sun

40 million Kelvin

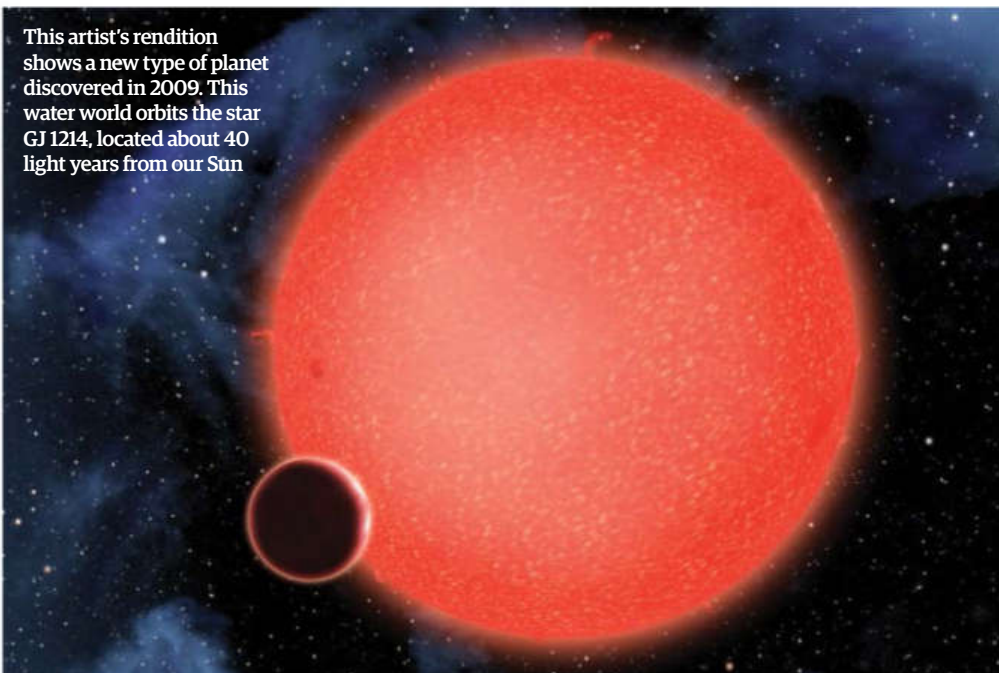
Although it's smaller than the Sun in mass and diameter, Proxima is 40 times denser than the Sun

*The flares on Proxima Centauri can reach this temperature - hot enough to radiate X-rays*

4.24

*Light takes this many years to reach the Earth from Proxima*

This artist's rendition shows a new type of planet discovered in 2009. This water world orbits the star GJ 1214, located about 40 light years from our Sun





# Exploring the stars

Could we travel to this distant neighbour and what problems would we encounter on the way?

Although Proxima Centauri is sometimes referred to as Alpha Centauri C, we aren't yet sure how it fits in with Alpha A and B. The stars in the binary system orbit around a common centre of gravity, and range from being 1.67 billion kilometres (1 billion miles) to 5.3 billion kilometres (3.3 billion miles) apart due to the eccentricity of their orbit. They're relatively similar and Sun-like.

By contrast, Proxima is smaller, redder, weaker and much further from the other two stars. Visually it appears as a faint red star near two very large bright stars - it doesn't seem to fit. However, Proxima has the same proper motion as Alpha Centauri AB;

the angular changes in position over time are the same. Proxima could have been pulled into the system by the older stars, or formed at the same time.

Alpha Centauri and Proxima Centauri in particular, as the closest star to us after the Sun, is theoretically our first stop once we figure out the particulars of interstellar travel. Although it's close in terms of stars, the distance is the biggest challenge. We could get there, but it's going to take a long time. Using our current technology, it would take thousands of years. The Voyager 1 space probe has travelled further than any other, and is currently travelling in previously unknown

space territory at around 60,000 kilometres per hour (38,000 miles per hour). If it were heading to Proxima, Voyager would take more than 70,000 years to reach the star.

In 2011, NASA's Ames Research Center and the Defense Advanced Research Projects Agency (DARPA) began collaborating on the 100-Year Starship Project. The purpose was to determine the requirements for meeting the goal of human interstellar travel within a century. Some currently feasible ways of reaching Proxima include ion propulsion engines and solar sails. The former creates thrust by accelerating ions, while solar sails harness radiation pressure of gases to

push thin, sail-like mirrors to high speeds. Both concepts have been tested, but have not yet been used as a primary source of power.

There is also a human cost to interstellar travel. If it's not possible to reduce the amount of time it takes to reach Proxima, we'd need multiple generations of astronauts; children would be born along the way and have to pick up where their parents left off. Even if we could get there in a century, that's longer than the average human lifetime. Space travel also causes bone and muscle loss, and the cardiovascular system loses some of its efficiency. There's also the matter of supplying and maintaining a spacecraft for a number of astronauts, for the trip there and back. Distance is just one challenge on our quest to reach the stars. ■



## Seeing the star

Proxima Centauri might be a relatively small and dim star (being a red dwarf), but that doesn't mean it's only visible to the most sensitive telescopes - it can even be seen with a pair of binoculars from Earth. However, because it's so close to Earth it has become a subject of exoplanet hunters in recent years and for that you need some serious hardware, well beyond the most fervent of amateur stargazers. Since the hunt for exoplanets escalated among the space agencies in the Nineties, Hubble, ALMA and Kepler have trained their instruments on this nearby star.

NASA's Hubble Space Telescope (inset) and the European Southern Observatory's ALMA (Atacama Large Millimeter/submillimeter Array) in Chile, are among the most famous of the observatories that have scrutinised Proxima Centauri



## Mass matters

### Alpha B

**0.907 Solar mass**

As the secondary star in the system, Alpha B is slightly smaller. It is more orange and a K-type main sequence star - cooler than Alpha A and the Sun

### Proxima

**0.123 Solar mass**

Proxima Centauri is tiny in comparison to the other stars in the Alpha Centauri system. It is about 4.85 billion years old; potentially older than our Sun but a great deal smaller. It's an M-type star, either main-sequence or sub-dwarf

### Alpha A

**1.100 solar mass**

Both Alpha Centauri A and B are estimated to be between 5 and 6 billion years old. Alpha A is just a bit bigger than our Sun, and a G-type main sequence star with a similar yellow colour

### Sun

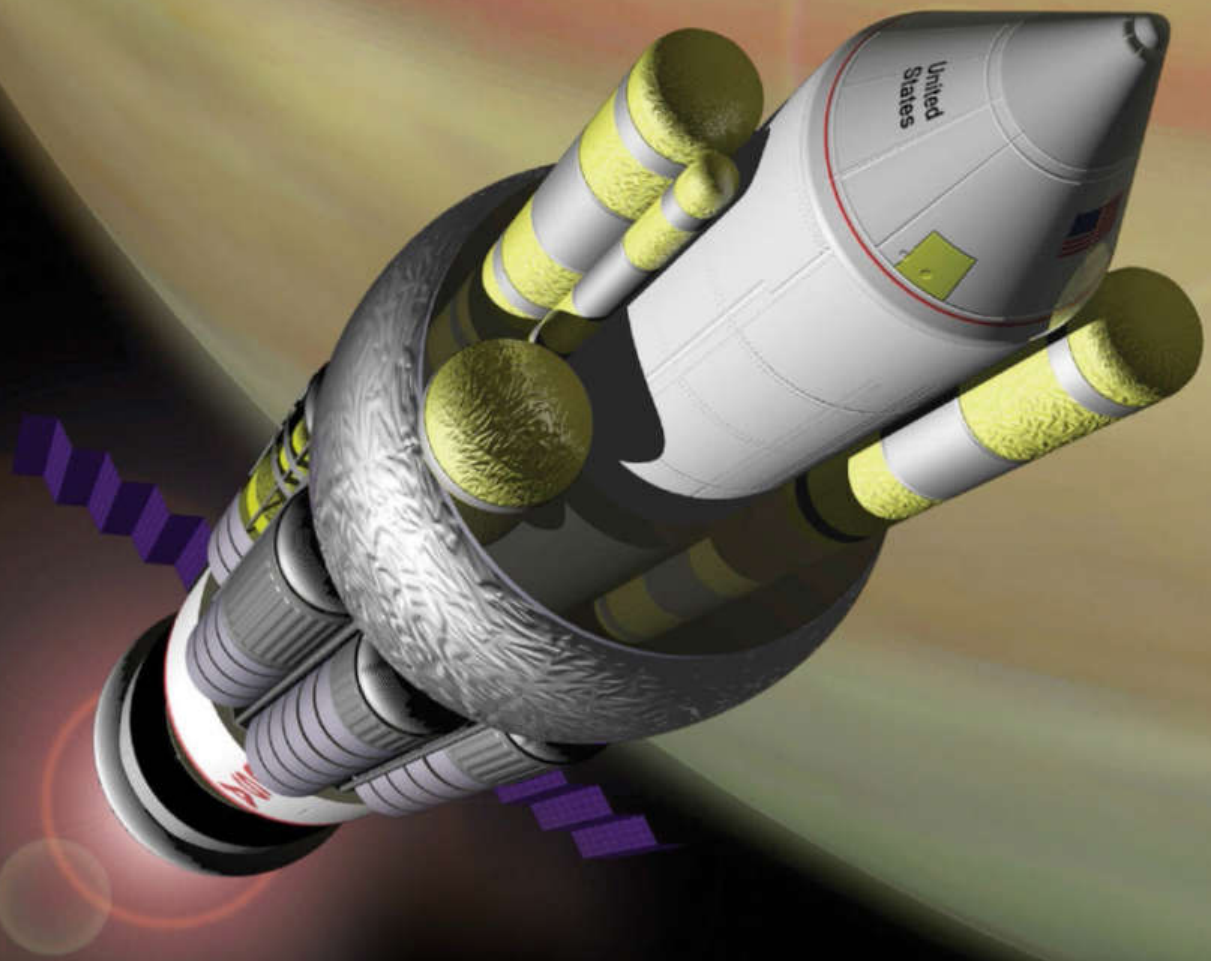
**$1.989 \times 10^{30}$  kg**

The Sun is 4.6 billion years old and a G-type main sequence star, sometimes called a yellow dwarf. It's very similar to Alpha Centauri A

## Interstellar travel

We've long been studying ways to achieve interstellar travel. In the late-Fifties, NASA had Project Orion. This spacecraft would have used nuclear pulse propulsion - a series of exploding atomic bombs - to propel it the distance needed to reach Mars, Saturn and ultimately another star. The British Interplanetary Society studied the possibility of a spacecraft to the stars in the Seventies, called Project Daedalus. Daedalus had the goal of taking no longer than a human lifetime to reach its destination, requiring a speed greater than the capabilities proposed for Project Orion. It would have needed a very powerful fusion rocket. Then, in the late-Eighties, NASA tried again with Project Longshot, an unmanned probe designed to be built and launched at Space Station Freedom, the predecessor to the International Space Station. Instead of a closed fusion rocket for power, Longshot would have used a nuclear fission reactor.

So what happened to keep these projects concept only? For Orion, the Partial Test Ban Treaty, signed in 1963, rendered it impossible. The treaty banned the test detonation of nuclear weapons, except underground. Both Project Daedalus and Project Longshot require significant advances in nuclear fission technology to be viable. Today we don't have the ability to get to Proxima Centauri in less than a thousand years, much less a hundred years.



This artist's rendering shows NASA's Project Orion, a spacecraft study in the Sixties that had aspirations of interstellar travel



# When galaxies collide

These two interacting galaxies are providing us with a rare opportunity to observe a galactic collision

This stunning image, taken by the Hubble Space Telescope, shows the individual galaxies UGC 1810 (top) and UGC 1813 (bottom) in the process of colliding. Together, this pair of interacting galaxies is known as Arp 273. The interaction of galaxies is thought to be relatively common in the universe, particularly within galactic clusters, however, the opportunity to directly observe one such as this is incredibly rare.

The two galaxies are located around 300 million light years from Earth in the Andromeda constellation. A collision is actually thought to have already occurred, with UGC 1813 passing through the five times more massive UGC 1810. As a result, the smaller galaxy is now showing signs of intense star formation at its nucleus. It is possible, though, that they will collide again in the future due to their gravitational attraction.

Most galactic collisions result in the merging of the two galaxies' cores, but it's unknown if that will happen in this example. What can be seen is a 'bridge' of sorts between the two where their spirals have been pulled apart by the other. It is thought that the interaction of Arp 273 may bear similarities to the eventual fate of our own galaxy when we collide with Andromeda in around four and a half billion years. ■



When galaxies collide





# The Sombrero Galaxy

The space phenomenon that's two types of galaxy at once

Located approximately 28 million light years from Earth, this odd-shaped galaxy has been the focus of much attention from scientists around the world. The Sombrero Galaxy, or Messier 104, gets its name from its somewhat hat-like appearance. The bright galaxy is found towards the southern edge of the Virgo cluster of galaxies.

The Sombrero Galaxy contains about 2,000 globular clusters, collections of up to a million old stars held together by gravity that are often found in the halo of galaxies. By comparison, our Milky Way

only has about 200. The Sombrero also contains several hundred billion stars and is approximately 50,000 light years across, around half the diameter of the Milky Way.

Around the brim of the galaxy are thick dust lanes that block the light at the centre, while the central bulge is made of old stars. Although the disc might be thin, the bulge, containing a black hole billions of times more massive than the Sun, can be seen extending both above and below the galaxy in this image from NASA's Hubble Space Telescope.

One of the most interesting things about the Sombrero Galaxy is that it seems to have a split personality. Most galaxies we know of are either spherical clusters of stars or slender discs, but the Sombrero appears to be both. Observations by NASA's Spitzer Space Telescope suggest that it is a round elliptical galaxy with a flat disc inside. The cause of this unique structure is unknown, although it's possible the Sombrero Galaxy was inundated with gas over 9 billion years ago, forming this additional mini-galaxy within. ■







# Galactic ghosts

Eight shadowy galaxies that were briefly lit up by a powerful blast of energy





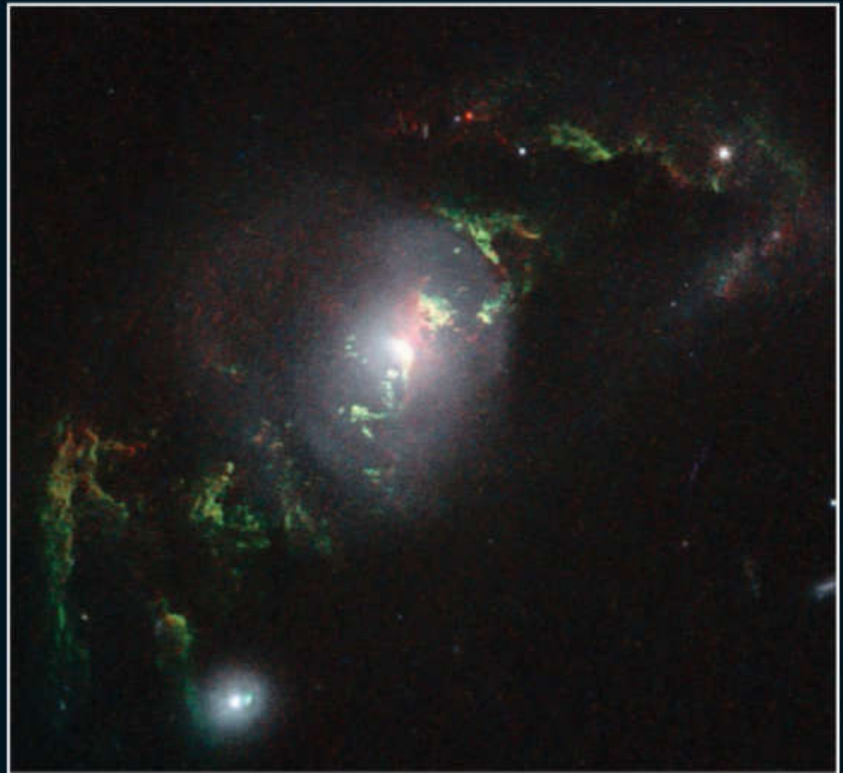
Each of these wispy celestial objects is a galaxy photographed by the Hubble Space Telescope. Most of the filaments that surround them, which show up mainly in green, were practically invisible until the energetic quasar that surrounds the supermassive black hole in their host galaxy lit them up with an extremely powerful blast of radiation. This caused elements in the filaments, including oxygen, helium and sulphur, to absorb the energy and release it gradually as light. Each element glows in a different

colour and green, the most abundant colour in these images, is ionised oxygen. The process is called photoionisation and the filaments will glow for many thousands of years after having been ionised - although this period is just a blink of an eye on a cosmological scale.

The far left image on the top row shows the Teacup galaxy. A supermassive black hole at its core is actually blasting away the raw materials needed for continued star formation. ●

The once-invisible filaments of these galaxies have been illuminated by the radiation that surrounds their supermassive black holes

© ESA





# Hypergiant stars

They're the biggest stars in the universe - cosmic monsters up to a million times brighter than the Sun - so how do supergiant and hypergiant stars push the limits of astrophysics?



Look up at the sky on a dark night, and you'll see hundreds of stars. But only a few will really stand out - have you ever wondered why? For some, it's simply because they're quite close to Earth. For instance, Sirius is just 8.6 light years away - so, even though it's a fairly average star (though still 25 times more luminous than our Sun) it appears as the brightest star in our sky.

But other stars appear bright because they really are. The second brightest star in the sky, Canopus, is one such star - 310 light years from Earth and some 15,000 times more luminous than the Sun.

Stars in this class are usually known as supergiants - they have the mass of ten or more Suns, and evolve in a very different way from lower-mass 'Sun-like' stars, living fast, squandering their nuclear fuel and dying young in spectacular supernova explosions. The most massive stars of all, containing many tens or even hundreds of solar masses of material, are hypergiants, the most extreme stars known.

"In astronomy I think there's a natural tendency to be attracted to extremes," explains Professor Paul Crowther from Sheffield University. "Whether that's the most extreme by physical size, which are generally the cool red supergiants, or the most extreme by mass, which are the hottest and brightest blue hypergiants."

And Crowther should know - he's devoted much of his career to studying these stellar monsters, and in 2010 discovered the most extreme hypergiant so far, a stellar beacon 165,000 light years from Earth in the independent Large Magellanic Cloud galaxy, an incredible 9 million times more luminous and 265 times more massive than the Sun.

Supergiants and hypergiants were first discovered through the theoretical tools of astronomy - in particular the Hertzsprung-Russell (H-R) diagram which allows astronomers to visualise the properties of stars en masse. However, the word 'giant' can be somewhat confusing, because in this case it combines concepts of mass and size. The largest stars by diameter can all be loosely defined as 'red giants' - an evolutionary phase that most stars pass through near the end of their lives, during which they swell to huge diameters (often larger than Earth's orbit around the Sun) and become far more luminous as they pump out more energy, but conversely turn red thanks to the coolness of their vast outer surfaces. The more massive a star is, the bigger it will grow as a red

giant, and red supergiants with tens of solar masses (such as VY Canis Majoris, with a diameter larger than Jupiter's orbit around the Sun) are indeed the largest stars of all. However, really monstrous heavyweight stars never actually reach this stage, so while the larger a red giant is, the more massive it will be, the most massive stars of all aren't actually the largest.

The most massive stars are born at the heart of collapsing star-forming nebulae, where gas and dust are most readily available. Unlike the more sedate, Sun-like stars, which form around the edges and coalesce over many millions of years, these stellar heavyweights grow to their enormous proportions in just a hundred thousand years. The overall amount of raw material in the nebula (reflected in the size of the star cluster that emerges from it) also has a role to play.

"There seems to be a broad relationship between the total mass of a cluster, and the most massive star within it - so for instance the Orion Nebula has a mass of 1,000 Suns, and its most massive stars are about 30 times that of the Sun, while the NGC 3603 cluster has about 10,000 solar masses of material, and its most massive stars weigh around 100 solar masses. We don't know quite why this 'mass function' is the way it is in young star clusters, but it seems to be a universal rule," says Crowther.

Competition between the massive central stars seems to act as a throttle to the formation process, ensuring that really massive stars are increasingly rare. "The next obvious question is whether if you had an even more massive cluster, would the mass of its biggest star keep going higher?" says Crowther. "And the answer seems to be no - we suspect there's a limit and it's linked to the star formation process. A star forms in a collapsing nebula full of competing stellar 'seeds', and it has a limited time to grab as much material as it can, or else its neighbours will. It's a bit like throwing a handful of sweets into a crowd of children - the ones nearest the centre will grab most of them really quickly, while those at the edges hardly get any. It's a competitive environment, and that probably puts an upper limit on how massive a star can get."

Another major difference between normal and monster stars lies in the nuclear reactions that keep them shining. In low-mass stars, these reactions are dominated by the 'proton-proton (p-p) chain', a process in which individual hydrogen nuclei

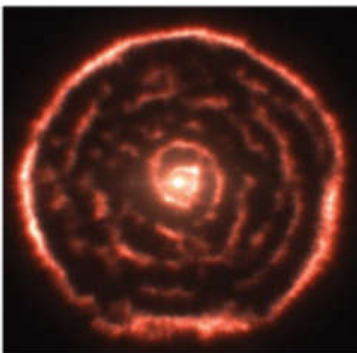


fuse together one reaction at a time, to eventually produce nuclei of helium, the next heaviest element. The p-p chain releases small amounts of energy at every step, but proceeds relatively slowly allowing Sun-like stars to keep shining for billions of years.

In more massive stars, however, another process called the CNO cycle becomes important. This fusion chain also converts hydrogen nuclei into helium, but it uses carbon nuclei as a sort of 'catalyst', allowing the reactions to happen at a much faster rate. The CNO cycle becomes increasingly dominant at higher temperatures and densities, and causes heavyweight stars to shine many thousands of times more brightly than their less massive neighbours. But the price for this brilliance is a drastically shortened life span - even though their cores contain much more nuclear fuel than those of Sun-like stars, massive stars exhaust themselves in just a few million years and begin to swell into supergiants or hypergiants.

This short life span means that supergiants are almost always found at the heart of newborn star clusters - these clusters disintegrate over millions of years, eventually scattering their longer-lived stars over a broad region of space, but supergiants simply don't live long enough to make it out of their stellar nurseries.

"These stars are incredibly rare - they only form in a few places and have very short lifetimes, so even if you find a star cluster that's just 5 million years old, its most massive stars will already have died," says Crowther. "There's only a handful of really young, massive clusters close enough to Earth for us to look for these guys and they're losing mass at a terrific rate, so the mass we measure depends on just how old the stars happen to be. The places where you usually find these really massive clusters tend to have enhanced star



This image shows a spiral structure in the material around the R Sculptoris star

## The size of stars

**Our Sun**  
Type: Yellow dwarf  
Solar Radii: 1

**Arcturus**  
Type: Orange giant  
Solar Radii: 25.7

**Sirius A**  
Type: White main sequence  
Solar Radii: 1.711

**Pollux**  
Type: Orange giant  
Solar Radii: 8.8

**Antares**  
Type: Red supergiant  
Solar Radii: 883

**Betelgeuse**  
Type: Red Supergiant  
Solar Radii: 1,075

**V509 Cassiopeiae**

**VV Cephei**  
Type: Red supergiant  
Solar Radii: 1,050

**VY Canis Majoris**  
Type: Red hypergiant  
Solar Radii: 1,420

"Supergiants simply don't live long enough to make it out of their stellar nurseries"



## Hypergiant stars

■ **Rigel**  
Type: Blue-white  
supergiant  
Solar Radii: 74

■ **Zeta-1 Scorpii**  
Type: Blue hypergiant  
Solar Radii: 103

■ **V509 Cassiopeiae**  
Type: Yellow hypergiant  
Solar Radii: 650

■ **V354 Cephei**  
Type: Red hypergiant  
Solar Radii: 1,520

■ **NML Cygni**  
Type: Red hypergiant  
Solar Radii: 1,650

○ **Our Sun compared  
to NML Cygni**  
At this scale our Sun would be  
smaller than a pixel on this page



## Types of giant stars



### Red supergiant

The biggest red giants are the largest stars in the universe, swollen to diameters of a billion kilometres or more by changes in their cores as they near the end of their lives. As they swell in size and brighten to hundreds of thousands of times solar luminosity, their surfaces cool to a distinctive red colour. But many scientists say these stars are supergiants rather than true hypergiants.



### Yellow supergiant

Yellow supergiants seem to be a rare intermediate stage, though again they get their name from their size and brightness rather than their mass. They seem to be red supergiants that have shed large amounts of their outer gas as they head towards a supernova explosion. In this photo of the 'Fried Egg Nebula', rings of ejected material can be seen surrounding the central star.



### Blue hypergiant

Blue hypergiants are the real heavyweights of the universe – tens or even hundreds of times more massive than the Sun, and millions of times more luminous. Their powerful gravity limits their size, so their surfaces are intensely hot. The young star cluster NGC 3603, shown here, contains one binary system whose stars contain a staggering 90 and 120 solar masses of material.

formation rates, usually due to galactic collisions or interactions."

So what do supergiants and hypergiants look like? The truth is that they're surprisingly varied – while the H-R diagram might suggest that they'd all have extremely hot surfaces and appear blue in colour, in reality they range across the spectrum of colours. Supergiants show the most variety, and it seems that their colours simply reflect the precise balance between the inward pull of gravity and the outward pressure generated by its radiation at a particular phase in their lives. This balancing act, known as 'hydrostatic equilibrium' governs a star's overall diameter and therefore its surface area: even highly luminous stars can display Sun-like yellow, or even cooler red surfaces if they are large enough for the heating effect of their escaping radiation to be thinly spread.

Most stars retain more or less the same mass throughout their lives, and therefore maintain the same gravity, so their equilibrium is mostly affected by changes to their luminosity as the nuclear reactions in their cores change and evolve – from this, we can work out that blue supergiants are still close to the 'main sequence' of stellar evolution, while yellow ones have begun to swell in size as they reach

## "The borderland between supergiants and hypergiants is filled with unusual stars"

the end of their lives. Red supergiants are even further along their life cycle, and are the largest stars of all.

But for really massive hypergiant stars, there's a different story. These stars never make it across to the red side of the H-R diagram – instead their brilliant radiation generates such huge pressure that it blows their outer layers away into space, exposing the interior and ensuring that such stars remain hot, maintaining blue or white-hot surfaces throughout their lives. This strong outflow of hydrogen-rich material gives itself away in a hypergiant's spectrum and is one of the key means of distinguishing them from really bright supergiants.

The borderland between supergiants and hypergiants is filled with a strange variety of unusual stars, and no two astronomers really agree on the precise dividing lines between them. For example, luminous blue variables are extremely bright stars that show long, slow changes in brightness with occasional outbursts, and include both supergiant and hypergiant stars.

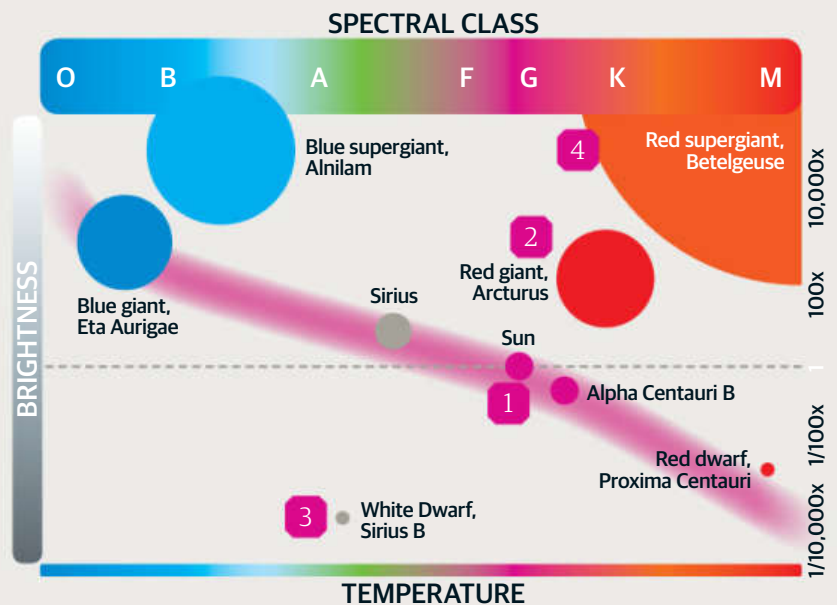
Most of the rare so-called 'yellow hypergiants', despite their name, actually seem to be red supergiants that are shedding their outer layers and heating up. And, as we've seen, astronomers also differ about whether red hypergiants even exist! Depending on their features displayed in their light, other categories of supergiant or hypergiant bear exotic names such as Wolf-Rayet stars and Ofpe stars.

However, until recently, the only certain means of weighing really massive stars, and identifying supergiants and hypergiants, was to pick them out in binary systems. Here, the orbital motions of the two stars can be used to calculate their masses. Fortunately, a recent breakthrough in modelling the behaviour of really high-mass stars promises to remove some of these limitations.

Supergiant and hypergiant stars live fast and die young, but what fate awaits them at the end of their lives? Once a star has exhausted the hydrogen fuel in its core, it has reached the end of its main sequence lifetime

## Star classification

One of the most useful tools for classifying stars is the Hertzsprung-Russell (H-R) diagram. It plots stars according to their surface temperature and colour or 'spectral type' (on the horizontal axis) and their luminosity (on the vertical axis). When a large number of randomly selected stars are plotted, a pattern soon emerges: most stars are arranged along a diagonal ribbon known as the 'main sequence', that runs between the faint, cool and red and the bright, hot and blue. Luminous cool stars and faint hot ones ('red giants' and 'white dwarfs') occupy regions to either side of the main sequence and are comparatively rare.



### 1. Main sequence

This is the region where stars spend the majority of their lives – a star's position on the main sequence is largely determined by its mass.

### 2. Red giants

Most stars pass through this phase near the end of their lives, brightening and developing an atmosphere with a cool surface.

### 3. White dwarfs

These hot stars are faint because of their tiny size – they are the burnt-out, slowly cooling cores of stars like our own Sun.

### 4. Supergiants

These high-mass stars are brilliantly luminous and display a variety of colours as they move back and forth across the H-R diagram.



# Structure of a supergiant

## Red supergiant

A red supergiant is a high-mass star that is nearing the end of its life and has long since exhausted the supplies of hydrogen fuel for fusion in its core

## Monster star

The largest red supergiants can grow to diameters larger than Jupiter's orbit around the Sun

## Still burning

The star's core keeps generating energy by fusion of heavier elements, growing denser over time

## Fusion shells

Meanwhile, nuclear fusion of lighter elements spreads out in a series of shells around the core

## Outer envelope

The huge amounts of energy coming from the core and its surrounding shells cause the star's upper layers to balloon in size

## Cool surface

The star's enormous size gives it a huge surface area, so despite pumping out huge amounts of energy, the surface remains relatively cool and appears red

## Convection cells

Huge currents within the outer envelope create rising and sinking masses of hot and cool gas, often giving the star's surface a blotchy appearance

## Iron core

Just before the star dies, a core of solid iron begins to build up. Unlike the lighter elements, iron fusion absorbs, rather than releases energy, triggering the core's collapse and a supernova explosion

## Heavier shells

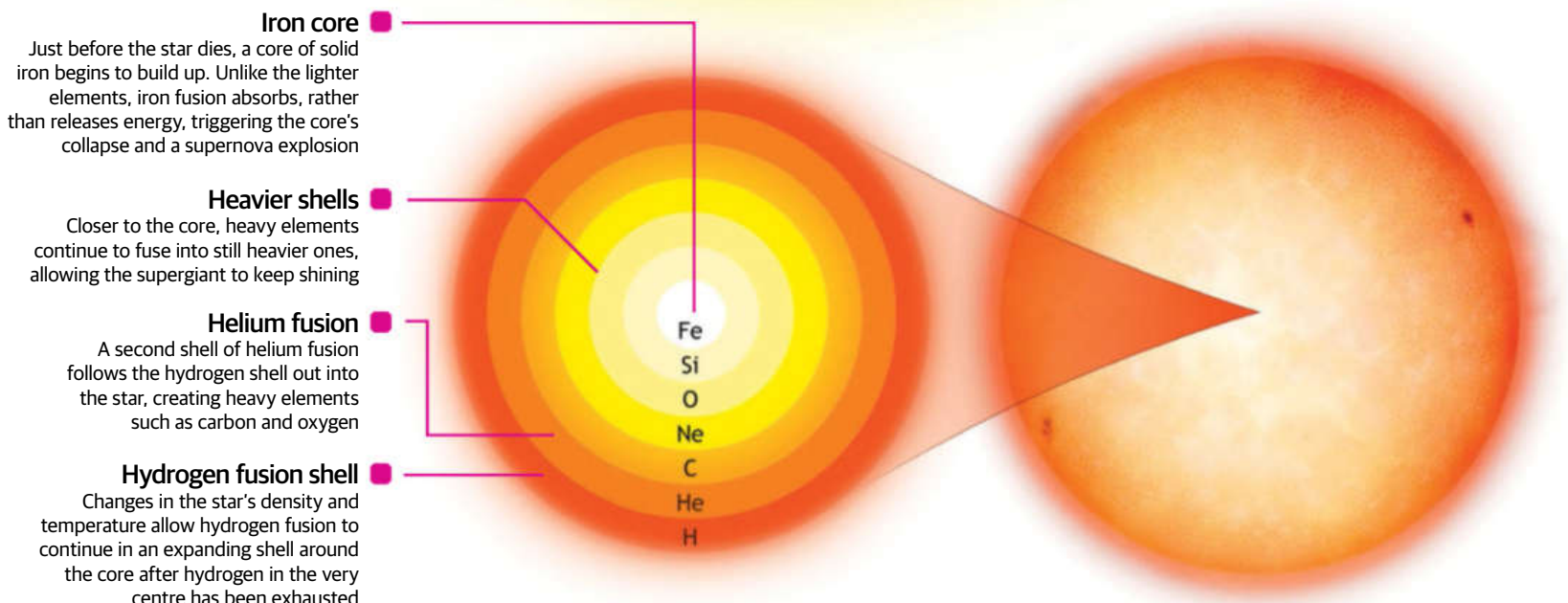
Closer to the core, heavy elements continue to fuse into still heavier ones, allowing the supergiant to keep shining

## Helium fusion

A second shell of helium fusion follows the hydrogen shell out into the star, creating heavy elements such as carbon and oxygen

## Hydrogen fusion shell

Changes in the star's density and temperature allow hydrogen fusion to continue in an expanding shell around the core after hydrogen in the very centre has been exhausted





and can only continue to shine by burning hydrogen from the shell surrounding the core, and heavier elements in the core itself. These processes cause the dying star to brighten and swell, shifting it towards 'red supergiant' territory, while its core develops a complex layered structure of increasingly heavy elements. Each new phase of fusion produces less energy than the previous one, and is exhausted more quickly, but the radiation that continues to pour from the core still helps to support it against its own enormous gravity.

That all changes when the star attempts to fuse iron – the first element whose fusion absorbs energy. Abruptly, the star's power supply falters and dies, and the huge weight of its outer layers comes crashing down. In what is known as a 'core-collapse supernova', the iron-rich core is compressed to a tiny size, while a tremendous shockwave rebounds through the remainder of the star, heating and compressing it until the whole star ignites in a blaze of nuclear fusion that may last for months and outshine a billion stars. As the supernova fades and the debris clears, the compressed remains of the core may be revealed as a super-dense neutron star, or even a black hole.

But, for the most massive stars of all, there may be a third option. "Theorists tell us that if a star dies with roughly 200 solar masses of material remaining, it could just blow up – it wouldn't be the usual core-collapse event, but a 'pair-instability supernova', which would blow itself to bits before it could form a super-dense core. These things would be amazingly bright and there have been a few observations of events that might be this kind of 'superluminous supernova'."

So, while they may be rare, these monster stars are certainly making their presence felt – and interest is only likely to increase in the next few years. Astronomers believe that supergiants and hypergiants would have been far more widespread in the early universe, when the lack of heavy elements would have given them a more compact structure with a hotter surface. Thanks to the expansion of the universe, the ultraviolet radiation that poured from the surface of these superhot stars should now be stretched or 'Doppler-shifted' to infrared wavelengths. Here it should be visible to NASA's James Webb Space Telescope when it launches in 2018 to give us our first view of the earliest stellar generations. ■

## Hypergiants in our galaxy

### Eta Carinae

Constellation: Carina  
Distance from Earth:  
7,500-8,000 light years

#### 1. Massive binary

The hypergiant Eta Carinae in the southern constellation of Carina is a binary system in which one star has at least 120 times the mass of the Sun, and is 5 million times more luminous.

#### 2. Violent outbursts

Eta Carinae is prone to sudden eruptions that cause it to brighten unpredictably as it hurtles towards an eventual death as a supernova.

#### 3. Homunculus Nebula

The star is still surrounded by this famous double-lobed nebula, ejected during its last major eruption around 1843.

### Pistol Star

Constellation: Sagittarius  
Distance from Earth:  
25,000 light years

#### 1. Pistol Star

This blue hypergiant in the Quintuplet Cluster close to the centre of our galaxy has the mass of around 100 Suns, and is 1.8 million times more luminous.

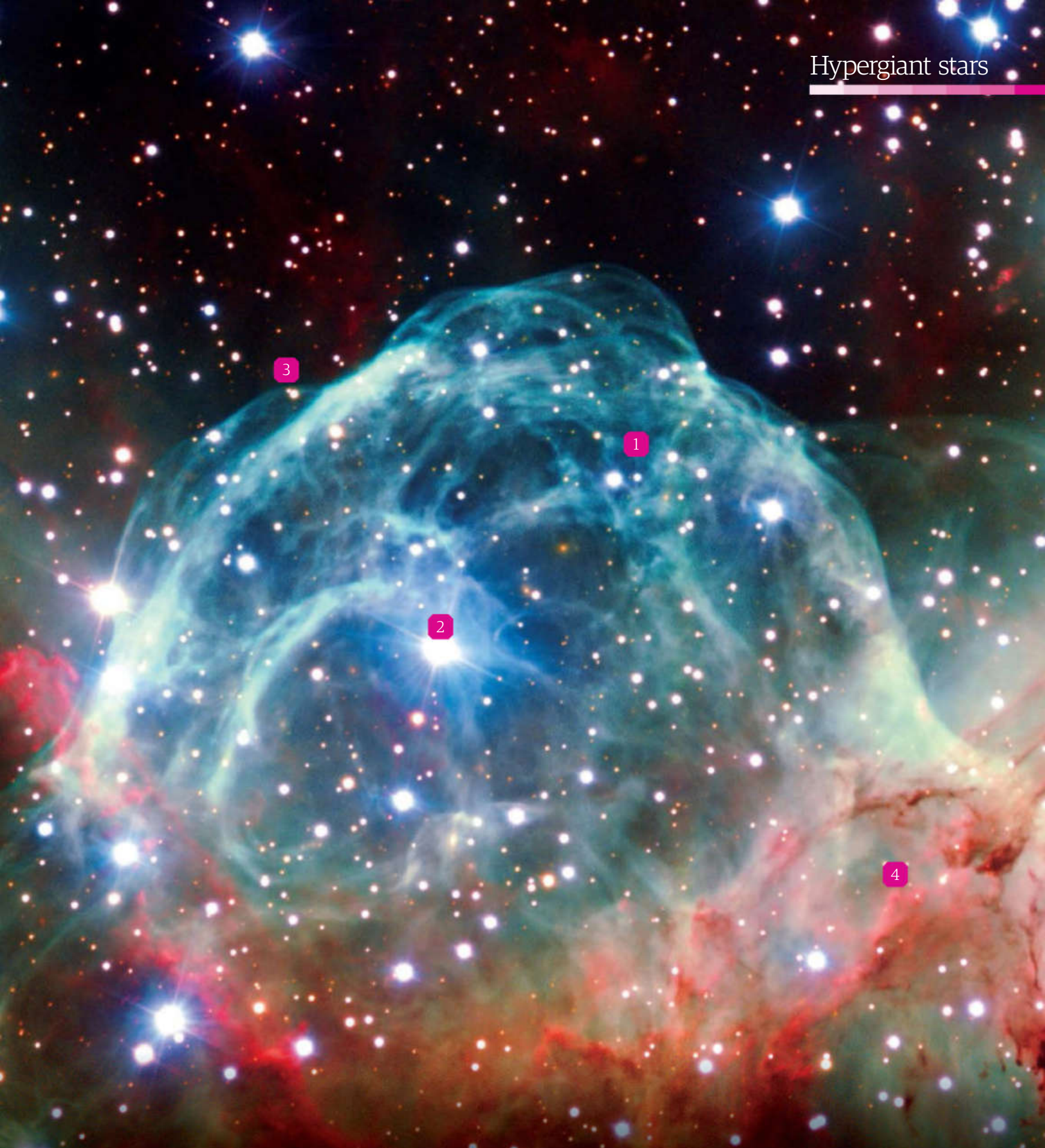
#### 2. Pistol Nebula

A nebula surrounding the Pistol Star contains roughly ten solar masses of material, ejected in a violent eruption several thousand years ago.

#### 3. Infrared view

The Hubble Space Telescope used its infrared camera to pierce the dust between Earth and the galactic centre, revealing this unique view of the star.





## Thor's Helmet

Constellation: Canis Major Distance from Earth: 15,000 light years

### 1. Thor's Helmet

This distinctive nebula, which is catalogued as NGC 2359, lies 15,000 light years from Earth in the constellation of Canis Major.

### 2. Wolf-Rayet star

The central star is a blue supergiant with a powerful stellar wind blowing material away off its surface – an object known as a Wolf-Rayet star.

### 3. Gas shell

As wind from the star collides with the nearby interstellar medium, it is heated and excited to release energy through light, creating a glowing gas bubble.

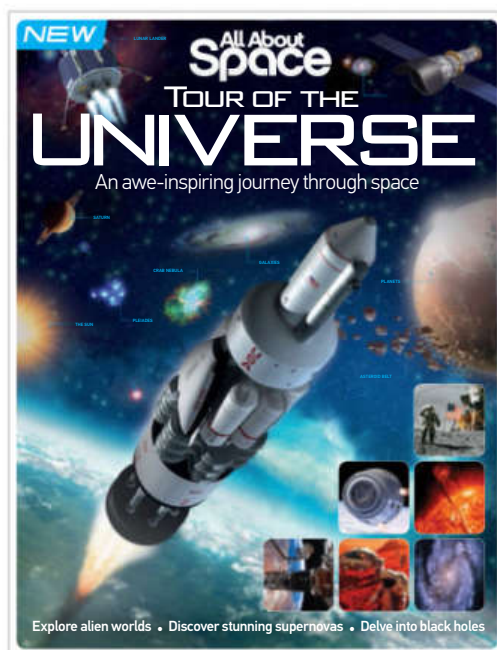
### 4. Swept wings

Collisions with interstellar material as the star travels through space create the nebula's distinctive helmet-like wings.



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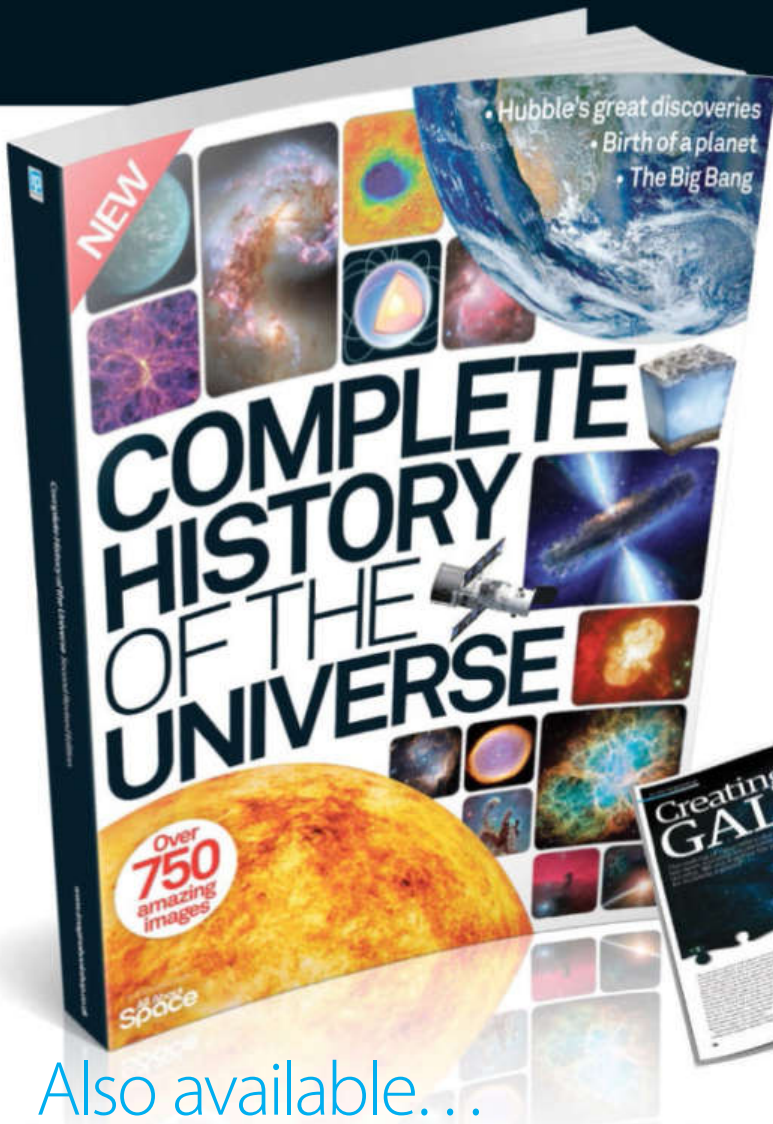
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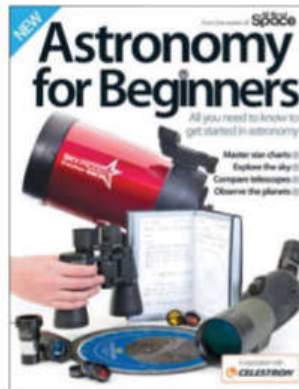
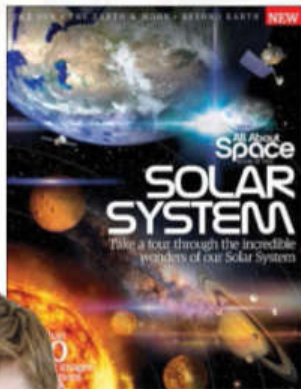
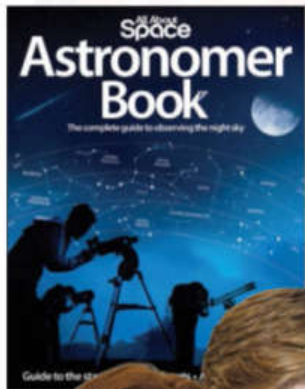
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